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ASSESSMENT AND EVALUATION OF SLAB ANALYSIS AND DESIGN PRACTICE IN ETHIOPIA (particularly in Addis Ababa and Mekelle)

*A Thesis Submitted to School of Graduate Studies of Addis Ababa Institute Technology
Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of
Masters of Science in Civil Engineering (Structures Major)*

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IV. ABSTRACT

The analysis and design of plate elements is too complex, for most cases there is no closed form of solution for these are highly intermediate structures which are full of assumptions, and uncertainty makes difficult for day to day application and become uneconomical during design. To tackle this, researchers and engineers developed simplified method with acceptable reliability and accuracy. Still the limitation is visible that some methods are only applicable to some particular problems. Hence to control this, codes were prepared and used in practical analysis and design practices and used to harmonize the application throughout the country. But many professionals claim that the practice is not to the standard and may damage the economy of the country as whole if some devastating earth quake happens. Moreover, these believes care shall be taken in design, construction and service of the buildings for the country is under development, projects are becoming cost intensive and massive in terms of size (in which large number of occupants may use it).

It is clear that buildings shall be safe, economical and serviceable. But is very difficult to attain these requirements the same time , that is, these may need more time, finance and experience with knowledge. Almost all designers claim that the cost provided by most clients extremely unaffordable and time that they required for analysis and design is too short which leads for inexperienced and unqualified designers to join the practice on the contrast the well experienced go to large projects. For instance, in this research, it is identified mechanical engineers participate in design of buildings knowing the analysis software alone.

Hence, this study focuses on the actual practice of slab analysis and design assessment and evaluation. It covers international and local challenges faced during analysis and design, approval and construction (partly) of slabs. It compares and clarifies our code of practice with respect to related international code practice and re-evaluates the country local practical (particularly Addis Ababa and Mekelle) practice with our code of standard. Moreover, present and clarifies the methods of slab design and analysis stated in our code

Therefore, it is important to find the strength and weaknesses of the practice which helps us to provide up-to-date solution prior to damage and crises happened during earth quake, building function change and long age. And helps us to recommend further researches and control the application of the proclamation and codes throughout the country.

1. INTRODUCTION

Slabs are important load bearing structural elements in house-building and in industrial and high-rise buildings. A very high percentage of the total volume of concrete used for the construction of buildings is used for the realization of slabs; see table below. Consequently, as slabs have an important impact on the total cost of the construction, optimal design is necessary.

Percentage of the total concrete volume used for the realization of the main load bearing structural elements in buildings (WIGHT, 2009)

Table 1 Cost of structural part of building

Structural element or load bearing member	Percentage of total volume of concrete
Foundations and ground supported slabs	22%
Bearing walls	4%
Columns	5%
Slabs (elevated or framed slabs)	59%
Others	10%

The above table shows slabs take the highest cost over the other structural load bearing members. Moreover, the analysis and design of these slabs is too complex, tedious and could lead to error in design and construction. In advance for slab Cases with complex loading, shape, and support condition, the analysis and design become very difficult and uneconomical in computation time.

Problem statement

The analysis and design practice in Ethiopia is not done by well qualified and experienced registered structural engineers, thus the practice is found at lower standard, due to the lack of practice, experience and having the economical challenges.

2. OBJECTIVE OF THE STUDY

Slabs are plates and possess continuous support which makes them highly indeterminate structures, which possess 6 moment equations coupling each other, which makes them to lack closed form solution. Hence, their solution is difficult to obtain. Even for regular Geometry, support condition and simple load pattern, we have only few closed form solution, still the solution is complex and tedious. However, practically supports conditions are not regular, actual loading are highly variable and irregular. For such reason the complexity becomes beyond the theoretical capability. Hence, simplified engineering

solutions are important but with plenty of assumptions. To have consistent and simple design of slabs throughout the country, codes present simplified methods and procedures.

The Ethiopian building code standard was prepared based on Euro codes (which were not finalized at that time). It was assumed the Europe and Ethiopia share to some extent similar conditions than the other part of the world. The effort made to complete the code (EBCS) from incomplete Euro code undeniably was great. Some information was derived from ACI and BS.

Giving due respect and honor to the effort made to produce new and modern code (prepared in 1995) based on international practice; the code is believed to provide the minimum requirement and data. However, like the developed countries which correct errors, revises and amended their code through time. Similarly, for one, our codes were the 1st code for the 1st time. Secondly the code was derived from incomplete Euro code. For this reason it is not wise to conclude the code perfectly completed but rather it might have errors and may lack relevant information, clarity, easiness, completeness, directivity to other information. Many developed countries update their code from time to time. Similarly their proclamations recommend for amendments at relevant time. In our country, The Ethiopian building code of standard (EBCS) was prepared in 1995 G.C. it has been more than 20 years without any amendment and revision. Besides, there are no supporting materials and commentary on the code to implement throughout the nation. We have only few experienced engineers as we see nationwide, the lack of well experienced and practicing engineers put its role in slab design challenge. The cost of the design is one problem in creating the most safe and economical slab, as per the study of (WIGHT, 2009) the cost on slab is about 59% as compared to the other structural component and the new era in development of our country needs well engineered slabs incorporating safety and economy.

Hence, the general objective of this study is to asses and evaluates the current practice of slab design and analysis in Ethiopia, particularly in Mekelle and Addis Ababa.

Further, can be the general objective of this research can be briefed as follows.

To asses and evaluate:

- i) The similarity, difference, discrepancy and weakness of our code with other codes such as, British standard, European code, American concrete institute and Indian standard.
- ii) Application of the code by professionals, that is;
 - Easiness of the code to understand and use
 - Clarity of information in the code
 - Completeness of the information in the code
 - Suitability of the methods for practical use
 - Lacks of information in the code

- Accessibility of the code
 - Directivity of the code
- iii) The capacity and experience of the designer with respect to our code and other codes and international practice of slab analysis and design.
- iv) The methods of design and detailing of slabs either developed locally or overseas, such as spread sheets, hand methods, software

And to show

- v) Economic implication of the current practice
- vi) Accuracy of the current practice
- vii) To filter out common problems in design and analysis

So as to give direction to

- Future code preparation
- Improve curriculum of universities
- Enhancing the control of building during approval and use
- Software developers
- Further research

3. LIMITATION OF THE STUDY

Slab design and analysis is vast in nature and complex in application and plenty number of variety of shapes, loading and support condition, moreover, considering cost implication, this research will only focuses on

- i) One way and two way solid slabs
- ii) Ribbed and waffle slabs which satisfies the requirement stated in section 3.7.5 of the code
- iii) Slab width less than 7m and thickness less 200mm
- iv) Slab monolithically casted with its support or well restrained with support.
- v) Only reinforced concrete is taken with property of Concrete Grade <50 Mpa and class I works and Steel Grade 300 to 500 Mpa
- vi) Codes are not latest
- vii) Year of design is 2012-2013 G.C
- viii) The category of occupants are taken A to E only

1) PLATE (SLAB) ANALYSIS

CONCEPTS OF PLATE THEORY AND THEIR GOVERNING EQUATIONS

LITERATURE REVIEW

The history of the growth in development of scientific plate theories and significant solution techniques is quite interesting.

It started on the American Revolution time period and finds Euler performing free vibration analyses of plate problems (Euler, 1766). German physicist, performed experiments on horizontal plates to quantify their vibratory modes (Chladni, 1802). Bernoulli then attempted to theoretically justify the experimental results of Chladni using the previously developed Euler-Bernoulli bending beam theory, but his results did not capture the full dynamics (Bernoulli, 1789). The French mathematician Germain developed a plate differential equation that lacked a warping term (Germain, 1826), but one of the reviewers of her work, Lagrange (1828), corrected Germain's results; "thus, he was the first person to present the general plate equation properly" (Ventsel and Krauthammer, 2001).

Cauchy (1828) and Poisson (1829) developed the problem of plate bending using general theory of elasticity. Then, in 1829, Poisson successfully expanded "the Germain-Lagrange plate equation to the solution of a plate under static loading. In this solution, however, the plate flexural rigidity D was set equal to a constant term" (Ventsel and Krauthammer, 2001). Navier (1823) considered the plate thickness in the general plate equation as a function of rigidity, D .

$$D \left(\frac{\partial^4 w}{\partial x^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} \right) = p_z(x, y) \quad (1)$$

Some of the greatest contributions toward thin plate theory came from Kirchhoff's thesis in 1850 (Kirchhoff, 1850). Kirchhoff declared some basic assumptions that are now referred to as "Kirchhoff's hypotheses." Using these assumptions, Kirchhoff: simplified the energy functional for 3D plates; demonstrated, under certain conditions, the Germain-Lagrange equation as the Euler equation; and declared that plate edges can only support two boundary conditions (Ventsel and Krauthammer, 2001). Lord Kelvin (Thompson) and Tait (1883) showed that plate edges are subject to only shear and moment forces.

In addition to his extensive summery of achievement already mentioned predecessors, love considerably extends the rigorous plate theory by applying solution of two dimensional problem of elasticity (love, 1926)

Kirchhoff-love's hypotheses are fundamental assumptions in the development of linear, elastic, small-deflection theory for the bending of thin plates. These assumptions are restated here from Michel bakhoum (1992):

1. The material of the plate is elastic, homogenous, and isotropic.
2. Deflections are small compared to the thickness of the plate (usually of the order of one-tenth the thickness).
3. Bending of plate due to lateral load is achieved by the translation of points of the middle surface¹ normal to its initial plane.
4. Deformations are such that the slopes of the middle surface are rather small.
5. The middle plane of the plate remains free of stress (neutral) during bending caused by the lateral loads.
6. Straight lines normal to the middle plane before deformation remain straight and normal to the middle surface during deformation and do not change in length. This assumption implies that effect of transverse shears on the deformation is neglected.
7. Transverse normal stresses are neglected.

The above assumptions are the foundation for plate bending theory that is usually referred to as the classical or Kirchhoff's plate theory.

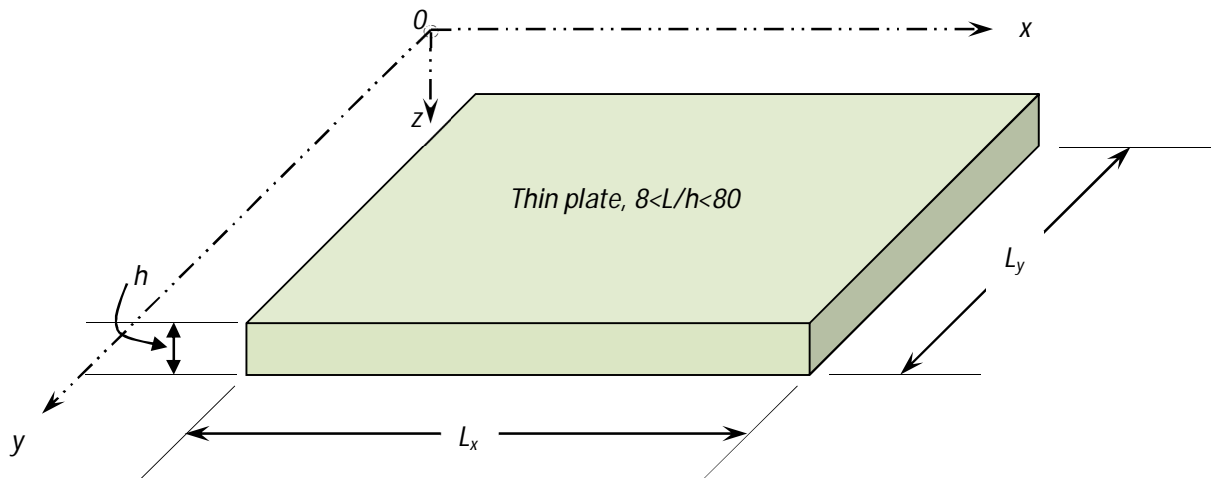


Figure 1 thin plate model

Thin plates are usually characterized by the ratio L/h (the ratio between the length of a side, L , and the thickness of the material, h , falling between the values of 8 and 80 (Ventsel and Krauthammer, 2001). Under Kirchhoff's hypotheses, the governing equation of motion can be derived for small deflections in thin plates as:

¹ Equivalent to the neutral axis of elementary beam theory.

$$D \left(\frac{\partial^4 w(x, y, t)}{\partial x^4} + 2 \frac{\partial^4 w(x, y, t)}{\partial x^2 \partial y^2} + \frac{\partial^4 w(x, y, t)}{\partial y^4} \right) = \rho h \frac{\partial^2 w(x, y, t)}{\partial t^2} \quad (2)$$

Where $w(x, y, t)$ is the deflection of the plate, ρ is the density, h is the plate's thickness, and

D is the flexural rigidity of the plate.

Levy (1899) successfully solved the rectangular plate problem of two parallel edges simply-supported with the other two edges of arbitrary boundary condition. Especially krylov(1863-1945)and is student Bubnov (1914)contributes extensively to theory of plates with flexural and extensional rigidities. Meanwhile, in Russia, Bubnov (1914) investigated the theory of flexible plates, and was the first to introduce a plate classification system. Bubnov composed tables "of maximum deflections and maximum bending moments for plates of various properties" (Ventsel and Krauthammer, 2001). Galerkin (1933) then further developed Bubnov's theory and applied it to various bending problems for plates of arbitrary geometries.

Timoshenko (1913, 1915) put numerous contributions to the further advancement of the theory of plate bending analysis; most remarkably, among his contributions are the solutions of circular plates considering large deflections and his development of elastic stability problems. Timoshenko and Woinowsky-Krieger (1959) wrote a textbook that is fundamental to most plate bending analysis performed today. Hencky (1921) worked rigorously on the theory of large deformations and the general theory of elastic stability of thin plates. Föppl (1951) simplified the general equations for the large deflections of very thin plates. The final form of the large deflection thin plate theory was stated by von Karman, who had performed extensive research in this area previously (1910). The von Karman equations (1910) governing the large deflections of thin plates are given by:

$$\frac{\partial^4 \Phi}{\partial x^4} + 2 \frac{\partial^4 \Phi}{\partial x^2 \partial y^2} + \frac{\partial^4 \Phi}{\partial y^4} = Eh \left[\left(\frac{\partial^2 w}{\partial x \partial y} \right)^2 - \frac{\partial^2 w}{\partial x^2} \frac{\partial^2 w}{\partial y^2} \right] \quad (3)$$

$$\begin{aligned} \frac{\partial^4 w}{\partial x^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} \\ = \frac{1}{D} \left(p + \frac{\partial^2 \Phi}{\partial y^2} \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 \Phi}{\partial x^2} \frac{\partial^2 w}{\partial y^2} + 2 \frac{\partial^2 \Phi}{\partial x \partial y} \frac{\partial^2 w}{\partial x \partial y} \right) \end{aligned} \quad (4)$$

Where w is the deflection of the plate, Φ is the stress function, E is the Young's modulus, h is the plate's thickness, p is an applied pressure, and D is the flexural rigidity.

These equations are coupled, non-linear, partial differential equations, both of which are fourth order. Unfortunately, this also makes them extremely difficult to solve analytically.

Reissner(1954) and Mindlin(1951) formulate reliable and efficient finite elements for thin plates. Direct application of these higher-order theories to thin-plate finite elements, however, often induced so-called shear locking behavior. To alleviate this undesirable effect, selective or reduced integration techniques were suggested.

Volmir and Panov are devoted mostly to solutions of nonlinear static plate problems. Ingerslev(1921). Johansen (1962) developed basically new approach to the static analysis of plates based on estimating the possible locations of fracture lines has been so called yield line analysis can be considered as the first important deviation from the classic theory of elasticity in the solution of transversely loaded plates. Hodge (1963) and Reckling (1967) extended the mathematical theory of plasticity to plates.

Nádai (1925) utilized finite difference method technique for the solution of practical plate problems using "longhand" calculation! This is straightforward numerical approach yields very usable results for a large Variety of specialized plate problems where analytical methods fail. The method is based on mathematical discretization of the plate continuum. Southwell (1940) rejuvenated the finite difference method. Stüssi and Collatz further improved it, which is still regarded as practical tool for plate analysis, despite the existence of the more powerful method (finite element).

In the late 1940s put forth the most remarkable pressure on the numerical analysis of plate structures due to the invention of electronic computers is observed. Hrennikoff (1941) had already developed an equivalent grid-work system for the static analysis of complex plate problems,

As already shown, structural plates have advanced significantly. Unfortunately, however, exact and approximate analytical solutions are limited to constant plate thickness and relatively simple boundary and load conditions. This could not satisfy the need of the design and construction industries. Their need fall on highly versatile and computerized procedure that could deal with all real-life complex plate problems in a basically uniform fashion.

In 1956 Turner, Clough, Martin and Topp introduced the finite element method, which was a basic tool for engineers and scientists to tackle highly complex problems of elastic and in-elastic continua in an economical way. Argyris(1963) and Zienkiewicz(1971)had put Numerous original contributions in this field. Then after, hundreds of papers are published every year dealing with all aspects of this very important numerical solution technique and concerned with extension and refinement of the finite element method as related to various theoretical and practical problems in this field.

In actual design of plates, alternative design schemes must be selected and evaluated before a final selection of the type of structural system to be used, which needs more comparative preliminary design evaluations, this can be done by practical design methods at minimum cost (economically).

In engineering applications of the theory of plates, it is clear there are pitfalls (errors) which should carefully considered, to name few,

1. Gross errors:-errors of caused by human and mechanical such as Round off errors, truncation errors, and ill conditioned matrix, to name a few.
2. *Inaccurate input data.*
 - a. In the first place, the external loads are known only with a certain degree of accuracy.
 - b. The material properties, such as the modulus of elasticity E and Poisson's ratio ν , contain considerable inaccuracies.
 - c. The actual boundary conditions of plate structures are merely an approximation of the theoretical ones.

3. *Output interpretation error.etc*

Consequently, even "exact" analytical solutions are merely approximations of the actual plate behavior under static loading.

Moreover, the *economy* of computational procedures must always be considered. That is, for reasons of various error sources inherent in all computations, as discussed above, a method that yields the required results in an economical way but has $\pm 10\%$ error of calculation is almost always selected over a more exact approach. **Plate analysis using engineering methods can always be accomplished by "long-hand" computations in a relatively short time.** Thus, these practical design methods do not require either computers or pertinent software. Some of these are stated here below.

ELASTIC ANALYSIS METHODS

Elastic web analogy is based on elastic theory and It was introduced by Marcus 1924 and to analyze continuous plate system. He developed approximation solution based assumptions that.

- The plate is elastic web with strips located at mid-span of the plate
- Load shall be uniform
- The neighborhood panel should not vary by more than 50%
- It based on aspect ration of I_y/I_x

Some alternative methods, which lead to very similar results, are available literatures and books:

- ✓ Grashof and Rankine
- ✓ the tables and graphs of CZERNY;
- ✓ the tables of BARES (1973);

The other method is simple and effective for practical reinforced concrete slab analysis developed by Pieper and Martens 1966. In this method the field moments at the center of individual panels can be calculated by taking the average of the corresponding field moments of plates with simply supported boundary conditions and those with completely fixed edges. To simplify this method, Pieper and Martens produce table of the pertinent constants which are given in table or graphical forms.

Assumptions

- ratios of the neighboring panels are smaller than 5:1
- the load shall be in the limit stated below:

$$P_{LL} \leq \frac{1}{3}q, \quad P_{LL} \leq 2P_{DL}, \quad (114)$$

Thus, the field moments at the center of plates with various types of boundary conditions can be obtained from:

$$m_{fx} = \frac{ql_x^2}{f_x} \quad \text{and} \quad m_{fy} = \frac{ql_y^2}{f_y} \quad (115)$$

Where

- f_x and f_y can be obtained from table **below** and l_x and l_y are the shorter and longer sides of the plate respectively.
- q is the sum of dead loads and live loads given by : $q = P_{DL} + P_{LL}$

For simply supported plates which are not properly anchored, one should use

$$m_{fx} = \frac{ql_x^2}{f_x^0} \quad \text{and} \quad m_{fy} = \frac{ql_y^2}{f_y^0} \quad (116)$$

Again, the corresponding factors are listed in table in Annex.

Similarly, negative moments at the supports are obtained by averaging the negative moments of plates with completely fixed boundaries, provided this average value is not smaller than 75% of the largest negative moment³. The approximate moment diagram of this method is shown in fig. ⁴

PLASTIC ANALYSIS METHOD

YIELD LINE METHOD

Although elastic theory of plates solutions yields good result for deformation and stresses, it doesn't tell us the ultimate load carrying capacity of the structure at failure load, At such condition (at

² The plate corners are assumed to be properly anchored with support.

³ This procedure is valid only if the span ratios of the neighboring panels are smaller than 5:1, if this is not the case Pieper and Martens produces charts attached in ANNEX_____

⁴ it is noteworthy to mention that the method of Pieper and Martens can also handle cases where only three edges meet at a corner point.

failure) the elastic theory⁵ become no longer valid, the other problem of elastic method is they are mathematically complex.

Although most plate problems can be solved by numerical method using computers extensively, the yield line can be used to check computerized solutions. Hence it is an alternative computational method for RC slabs.

Kazinczy, 1914 observed that the ultimate load carrying capacity of clamed steel beam was considerably higher than the predicted by elastic theory which is due to ductility of the material.

By introducing an idealized stress strain relationship and rectangular stress pattern, the true moment capacity of the section is given by

$$M_u = \int_{(A)} Z\sigma_y dA = \sigma_y \int_{(A_1)} ZdA - \sigma_y \int_{(A_2)} ZdA = \sigma_y \frac{bh^2}{4} \quad (117)$$

$$M_u = \int_{(A)} Z\sigma_y dA = \sigma_y \int_{(A_1)} ZdA - \sigma_y \int_{(A_2)} ZdA = \sigma_y \frac{bh^2}{4} \quad (118)$$

or

$$M_u = \sigma_y \frac{h^2}{4}, \text{ per unit length} \quad (119)$$

Further, Johansen 1943 extended the ultimate load analysis of beams and frames to RC slabs by introducing the concept of yield lines, olszak and sawczut, 1955 have demonstrated a good agreement between experiments and analytical solutions⁶:

In analysis of slabs using this method depends on the patterns⁷ of yield line, the optimum failure shall be identified this can be obtained by try and error. Procedure coupled with an iterative technique and needs experience.

When distributed and concentrated loads act simultaneously on a given slab, the determination of optimum yield line pattern become quite involved. Johansen's superposition theorem can be used, the ultimate moment can be written

$$m_{u1} + m_{u2} + m_{u3} + \dots + m_{uk} + m_{un} \geq m_{\Sigma p} \quad (120)$$

Where m_{uk} is the ultimate moment corresponding to the p_{uk} (ultimate load of yield line pattern)

$m_{\Sigma p}$ is the ultimate moment pertinent to the yield line pattern produced by the total load

⁵ most cases the elastic design is overly conservatives

⁶ Complex yield pattern can be taken from ready made patterns of pertinent literature.

⁷ When slab subjected to concentrated load or is supported by columns, the yield line analysis for bending must be always supplemented by checking the punching shear.

$$p_{u1} + p_{u2} + p_{u3} + \dots + p_{uk} + p_{un} \geq \sum_n p \quad (121)$$

Estimating of deflection

The approximate method of Marcus can be extended to obtain estimate of the maximum deflections produced by service loads.

METHOD 1

$$w_{max} = \frac{CM_{max}l^2}{EI} \quad (122)$$

(Based maximum load deflection)

Where C depends on the shape of the bending moment diagram, C is 1/8 for rectangular shape 1/8 to 1/10 for trapezoidal 1/9.6 for parabolic and 1/12 for triangle shape bending moments.

However the bending moment shape for yield lines are somewhat rectangle and the elastic theory yields parabolic moment distribution to compensate this problem, we can use average of the two shapes i.e $C = 1/9$ therefore,

METHOD - 2

$$w_{max} = \frac{1}{6} \frac{M_u l^2}{EI} \quad (123)$$

This can also be used for different boundary condition.

Where, l is the distance between the points of zero moment.

Assuming simply supported rectangular plates with uniform load the maximum deflection is given by

$$w_{max} = C \frac{5}{384} P_0 l_x^2 \quad (124)$$

STRIP METHOD

The strip method, introduced by Hilleborg, 1956 and developed by Wood & Armer, 1968 is also based on the assumption that reinforced concrete slabs behave plastically. However, the strip method, unlike yield line analysis, provides a lower bound on the collapse load. The strip technique is based on the lower bound or 'safe' theorem of plasticity. It involves finding a set of moments which are in equilibrium with the loads on the structure and which do not exceed the plastic moment capacity of the slab at any point.

The 'safe' theorem ensures that the collapse load factor associated with any statically admissible set of moments will be less than, or equal to, the true collapse load factor.

Consider the segment of slab and the associated moments and shear forces in figure below. The condition which must be satisfied for the element to be in vertical equilibrium is:

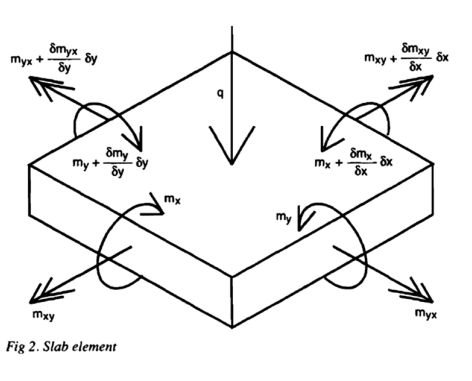


Figure 2 forces in plate

$$\frac{\partial^2 m_x}{\partial x^2} + \frac{\partial^2 m_y}{\partial y^2} + 2 \frac{\partial^2 m_{xy}}{\partial x \partial y} = -q \quad (124)$$

where m_x and m_y are moments per unit length on the X and Y faces, respectively, and m_{xy} presents the torsional moment per unit length. Hilleborg suggested setting the torsional term to zero and choosing m_x and m_y accordingly.

Setting the torsional term in equation to zero gives:

$$\frac{\partial^2 m_x}{\partial x^2} + \frac{\partial^2 m_y}{\partial y^2} + 0 = -q \quad (125)$$

This can be rewritten as

$$\frac{\partial^2 m_x}{\partial x^2} = -\alpha q \quad (126)$$

And

$$\frac{\partial^2 m_y}{\partial y^2} = -(1 - \alpha)q \quad (127)$$

Where α is a factor reflecting the degree of load sharing between the two orthogonal directions. Hilleborg's technique involves sharing the load at each point on the slab between two notional one-way spanning slabs which span in the reinforcement directions which are usually orthogonal as shown in Fig below.

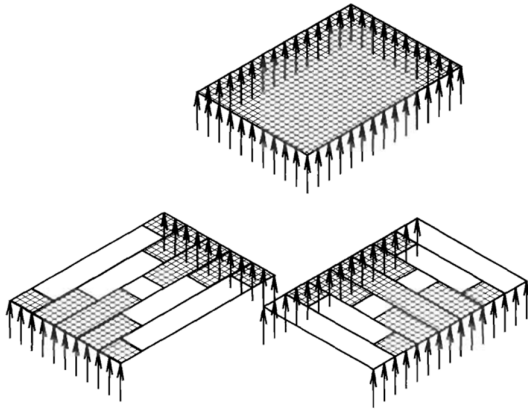


Figure 3 slab strips

The value of α determines how the load is divided between the X and Y directions. Hilleborg's approach does not require that the load on a given element be carried by spanning exclusively in either one or the other direction. Further, the value of α is not restricted to being between zero and unity. However, when Hilleborg's method is applied hand, the value of α for each section of slab is often set to either zero or one. Once the load has been allocated between the notional slabs spanning the two orthogonal directions, the one-way-spanning slabs are subdivided into strips and each strip is analyzed as an independent beam. As they are assumed to behave independently, the strip with the lowest collapse load factor dictates the overall collapse load.

2) RESEARCH METHODOLOGY AND DATA COLLECTION

To assess and evaluate the current practice of slab analysis and design in Ethiopia particularly in Addis Ababa and Mekelle cities, it will be very help full first to identify the stake holders which directly or indirectly participate in the processes of analysis, design and detailing and approval (based on legalization), construction and creating professional. These are consulting firms, contractor, municipality and universities.

Though it is difficult to truck the relation and knowledge and practice ex-change between the stakeholders, it can be summarized as figure below:

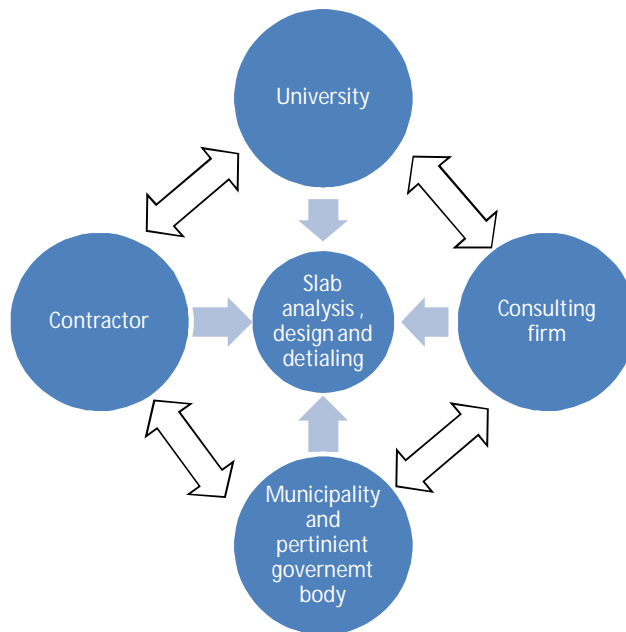


Figure 4 Stake holders participating in slab design and construction

Hence, the practice assessment and evaluations will be carried out based on their role in slab analysis. Though, the practice incorporates plenty methods of analysis, design and variety of professional experience status with variety of slab problems, it will be easy if the practice observed in different cases and evaluated, compare and contrast side by side

Case 1

In this case through evaluation, comparison and contrasting of our code (EBCS) with BS, EC, IS, and ACI (in relevant issues) are performed. This includes identifying similarity, differences, assumptions, and lack of information.

Case 2

Data collection of practicing engineers which mainly participate in such process. Interaction engineers with engineers, engineers with code, with international knowledge and practice, these include evaluating of clarity, simplicity completeness and availability of the codes and assess the professional experience and capacity using questioners.

Case -3

Critical evaluation of design documents approved in government bodies (specifically in municipality), this covers checking whether these satisfy the methods and assumptions in analysis, design and detailing and then compare of the methods design based codes and other literatures considering accuracy and economic implication.

3) SAMPLING AND DATA COLLECTION

GENERAL

Determining sampling is a complex task and involves much clarity with regard to the balance between the resource obtained and number or accuracy or information obtained. From a general perspective, sampling involves selecting representative (relatively small sample number of elements (characteristics)) from a large defined group so as the information gathered from the small group will provide accurate information to understand and judgment the large group of the population (paurav, 2008).

Considering the complexity of the subject matter and economy of the study, data availability and variation of data and cost of the research, Addis Ababa and Mekelle are taken as research area purposefully.

SAMPLING PROCEDURE

Consulting firms are the main stakeholder in analysis, design and detailing of slab and the other two stakeholders (municipality and contractors) which can be taken as verifiers for Consulting firms task and the fourth stakeholder can be taken as knowledge and professional supplier to the practice, hence the cross relation between those will help us to trace where the weakness can be founds, and tales the type and degree of the problems. This could finally lead us to good solution of improving the future practice.

SAMPLE TYPES

CONSULTING ENGINEERS AND UNIVERSITY ENGINEERS

Consultants registered up 2012/13 G.C. which participates in building design and supervision.

Table 2 number of registered consultants

Grade	Number Consulting firms	
	Addis Ababa	Mekelle
I	44	NA ⁸
II	19	NA
III	101	NA
IV	58	NA
V	82	NA
VI	2	NA
VII	0	NA
VIII	2	NA
Total	308	27

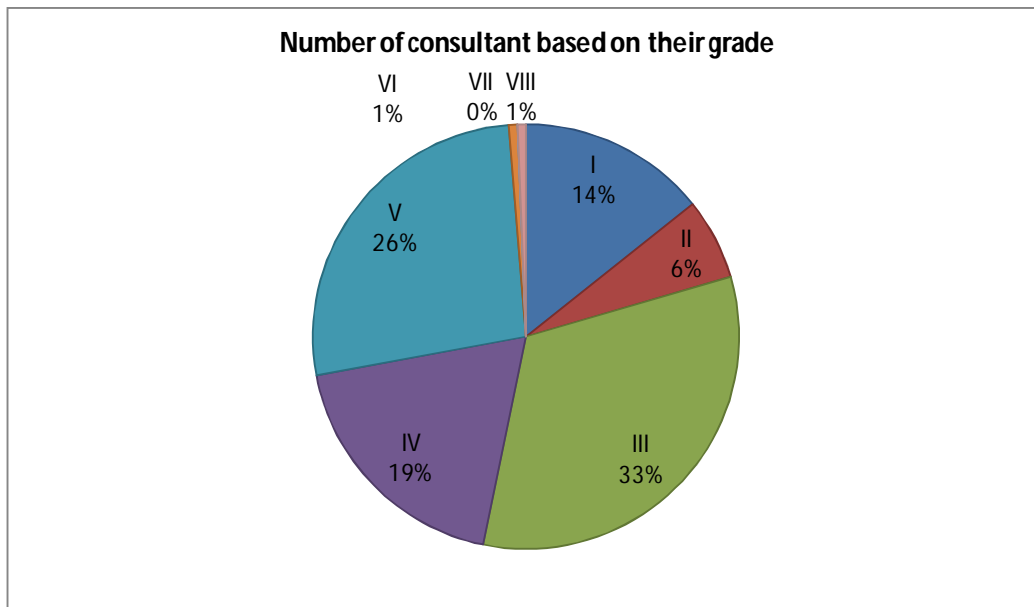


Figure 5 number of consultants in Addis Ababa and Mekelle (Data is from Addis Ababa Administration housing and development office)

Out of the total number of consultants and university engineers 415⁹(335 from consultants and 80 form university, about 15% (63 samples) are taken as representative data. In contrast to number of consultant, samples are small, this is because, the economy challenge in data collection.

MUNICIPAL ENGINEERS

The number of municipal engineers are very few in number, hence only 6 samples are taken as representative.

⁸ NA implies "not applicable" because the grading methods of the cities are different.

⁹ These are categorized under 1 category because university lecturer participate in consulting firms

CONTRACTOR

The number contractors are relatively large in number as compared to consulting firm and university lecturers, however, the general number of representative taken 4 samples, since these samples are required for verification.

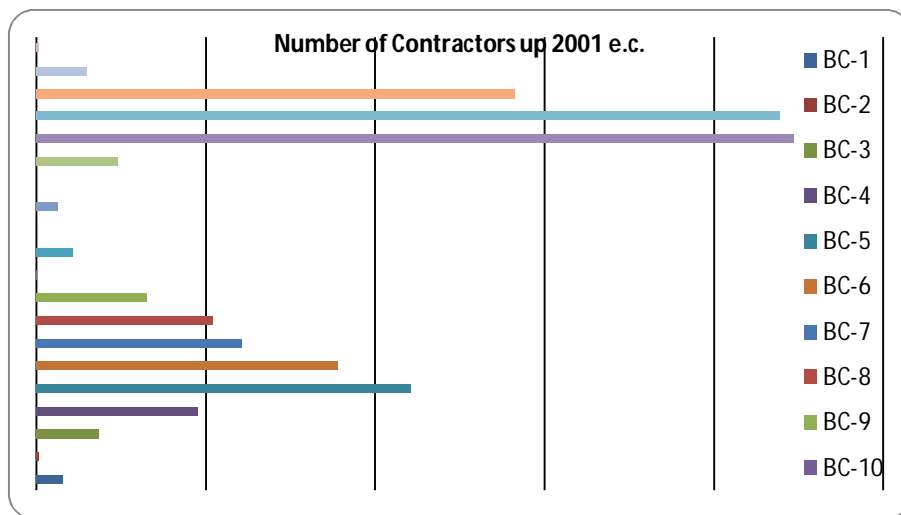
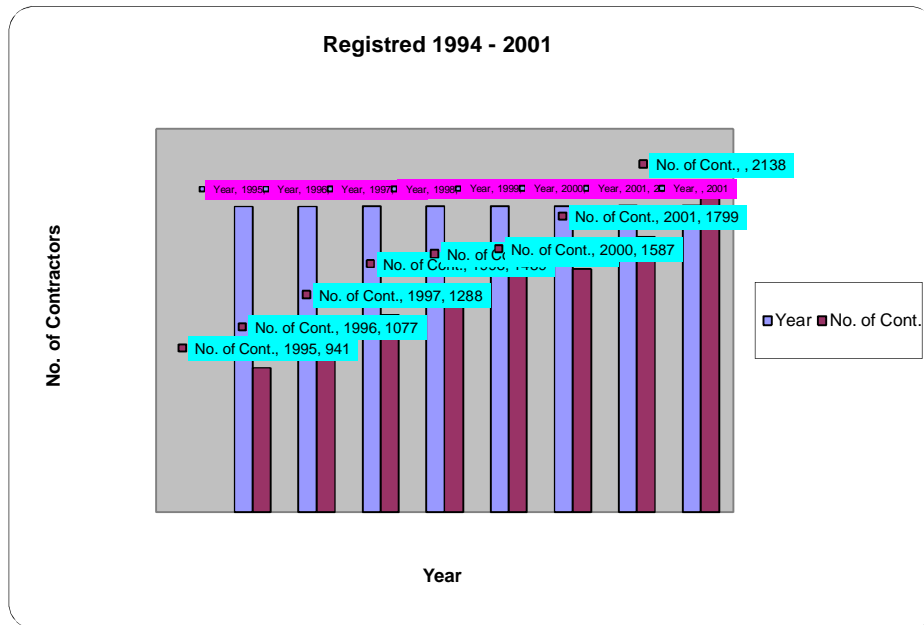


Figure 6 Number of contractors registered up to 2001 but still working (data source: ministry of works and urban development webpage)

SAMPLE DOCUMENT

Documents which are going to be assessed and evaluated in this research are classified in to three types these are;

- i) Codes
- ii) Design report

iii) Design drawings

Even though there are about 5 international codes are in hand including EBCS, the codes are not latest editions. Moreover, it is also very difficult to find design report and drawings from municipality, because these documents are confidential and sensitive¹⁰. But 10 samples of design report are considered

Generally 75 samples are taken as representative samples.

4) QUESTIONER DESIGN AND SAMPLE COLLECTION

It is clear there are different cases, assumptions and methods of slab analysis, design and detailing and plenty question could be raised from different perspectives and practice level and experience. It is very difficult to incorporate all this issues in this research for economic and time limit. Hence, about 130 representative questions, this mostly rose by professionals and thought to fulfill the general practice. These are classified as questioner for Consultant engineers (CE), 77 questions, Municipality engineer (ME), 36 questions and Contractor engineers (CTE), 17 questions. Out of these, 12 are common for all engineers and 11 are common for Consultant and Municipality engineers. The style of the questioner includes choice and fill types, detail questioner information are presented in appendix A, The questions presented as follows:

Table 3 Number of Questions and category common for all respondents

Questioner for	General information of the respondent	General information about code	About loading	Slab types	Analysis and design methods	Depth check and deflection
Consultant engineers(CE)	4	2	5	1	28	16
Municipality engineer(ME)	4	5	0	0	6	0
Contractor engineers (CTE)	3	1	0	0	2	0
Common(C3) for CE, ME, CTE	3	3	0	0	1	0
common for(C2) CE, ME	3	6	1	0	0	0

¹⁰ Loan and bank cases

Table 4 continued from table 5

Questioner for	Concrete cover	Concrete and steel grade	Payment and economy	Self upgrade and teaching learning process	construction experience	recommendations	municipal Approval
Consultant engineers(CE)	1	7	2	3	0	0	0
Municipality engineer(ME)	0	0	1	0	0	0	0
Contractor engineers (CTE)	0	0	0	0	1	0	7
Common(C3) for CE, ME, CTE	0	0	0	0	2	2	1
common for(C2) CE, ME	0	0	0	0	0	0	0

The number of collected are not as expected, presented as follows

Table 5 sample size and number of samples collected

	Sample size	Sample collected	
Respondents	In number	In number	%
Consultant engineers(CE)	63	10	16%
Municipality engineer(ME)	6	5	83%
Contractor engineers (CTE)	4	3	75%
Document codes	5	5	100%
Design report	10	10	100%

Although, the number of samples distributed are about 63 for Consultant engineers (CE) the number of sample collected are about 10 which accounts 15% of the total Consultant engineers (CE), the basic reason they are too busy and un-willing to give information¹¹. The standard deviation of the data collected is presented below.

¹¹ It unclear that they close their door for such information, but I would like to thank for those who open their door and show their willing for research.

Table 6 Standard deviation of the sample collected

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
v1	10	1	4	1.80	1.135
v2	10	1993	2003	2001.00	3.055
v3	10	.5	16.0	6.500	5.1532
v4	10	.0	12.0	2.850	4.1234
v5	10	1	7	5.30	2.584
v6	10	1	2	1.60	.516
v7	10	1	3	2.10	.738
v8	10	1	3	1.90	.568
v9	10	1	3	1.70	.823
v10	10	1	3	1.80	.789
v11	10	1	2	1.80	.422
v12	10	1	3	2.40	.699
v13	10	1	3	2.60	.843
v14	10	1	4	3.50	1.080
v15	10	1	3	1.90	.568
v16	10	1	5	3.70	1.494
v17	10	2	5	4.00	.943
v18	10	1	3	1.70	.675
v19	10	2	9	6.80	2.741
v20	10	1	4	2.40	1.265
v21	10	2	4	2.40	.843
v22	10	1	5	2.50	1.269
v23	10	1	4	2.50	1.179
v24	10	1	5	2.70	1.829
v25	10	1	4	2.20	.789
v26	10	1	5	1.70	1.494
v27	10	1	4	1.70	1.160
v28	10	2	6	3.90	1.729
v29	10	1	4	2.10	1.101
v30	10	1	6	3.50	2.224
v31	10	1	4	1.80	1.033
v32	10	1	6	3.30	1.767
v33	10	1	8	4.70	2.751
v34	10	1	7	5.60	2.119

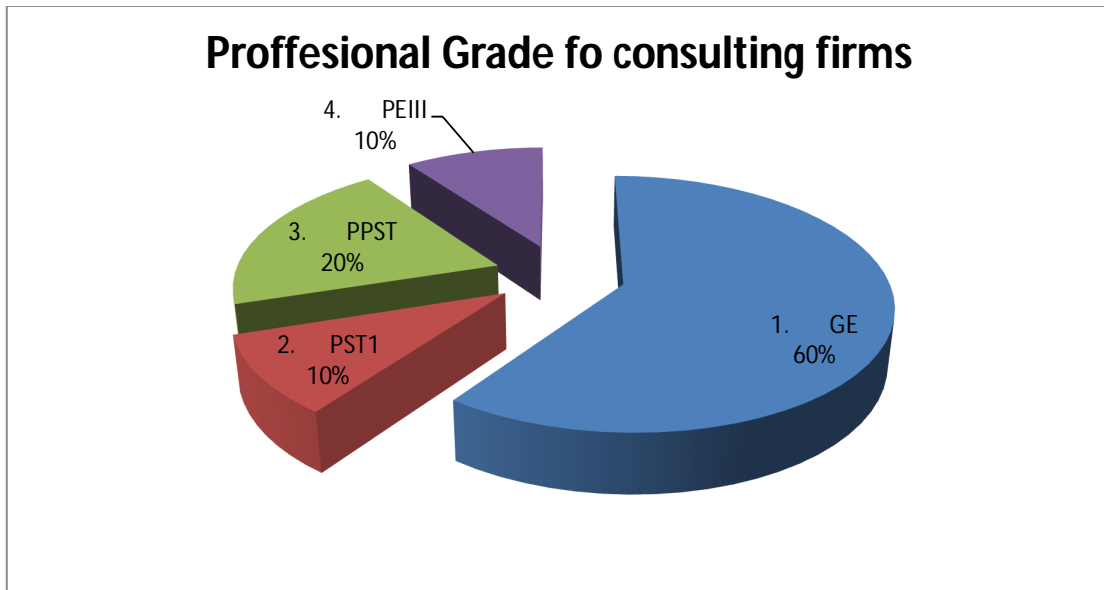
v35	10	1	4	3.30	1.160
v36	10	1	4	2.90	1.449
v37	10	1	4	3.30	1.059
v38	10	2	11	7.50	3.719
v39	10	1	9	6.10	3.071
v40	10	1	3	1.60	.966
v41	10	1	9	4.80	2.974
v42	10	2	3	2.90	.316
v43	10	1	4	2.20	1.317
v44	10	1	4	2.80	1.398
v45	10	1	4	2.90	1.197
v46	10	1	4	2.90	1.287
v47	10	1	4	2.50	1.179
v48	10	1	4	2.70	1.059
v49	10	1	4	2.90	1.101
v50	10	1	4	3.10	1.287
v51	10	1	4	2.40	1.265
v52	10	1	4	2.70	1.337
v53	10	1	4	2.30	1.160
v54	10	1	4	1.80	1.229
v55	10	1	4	2.30	1.252
v56	10	1	4	2.10	1.449
v57	10	1	3	1.70	.823
v58	10	2	7	4.50	2.121
v59	10	1	3	1.50	.850
v60	10	1	4	2.20	1.033
v61	10	1	10	6.20	3.393
v62	10	1	4	2.00	1.414
v63	10	1	4	2.60	1.350
v64	10	1	4	2.50	1.080
v65	10	1	14	8.80	4.940
v66	10	1	11	5.80	3.882
v67	10	1	4	2.30	1.160
v68	10	1	4	2.00	1.155
v69	10	1	4	2.30	1.160
v70	10	1	5	2.10	1.595
v71	10	1	5	2.20	1.549

v72	10	1	4	2.30	1.059
v73	10	1	4	1.90	1.197
v74	10	1	4	2.50	1.179
Valid N (listwise)	10				

PROFESSIONAL GRADE OF RESPONDENTS

CONSULTING FIRM

Most of the engineers responding (about 60% at consulting firm) are graduate engineers (GE) and only 20% are practicing professional practicing engineers (PPST).



Graduate engineer (GE), professional engineer (PE), professional structural engineer (PST), practicing professional structural engineer (PPST)

Figure 7 Professional grade of consulting firm

5) DATA ANALYSIS AND DISCUSSION

Considering the cases of sample assessment and analysis methods specified above, the first step is code and document evaluation and then data collection using questioner. These data are recorded and analyzed using software called statistical package for social science (SPSS version 16) and presented in a descriptive way in conjunction with all the cases.

CODE ASSESSMENT AND EVALUATION

BUILDING CODES OF ETHIOPIA

DEFINITION:

EBCS means the Ethiopian building code of standard

WHAT ARE CODES?

Building codes are developed and issued standard for design and construction work, and follow up and supervise the implementation thorough out the country is the same.

PURPOSE OF BUILDING CODES

- Serve as nationally recognized document.
- The application which is deemed to ensure compliance of building with the minimum requirement for design, construction and quality of materials set down by the national building code.

BENEFITS OF THE CODES

- Harmonized of professional practice.
- Ensure of appropriate level of safety health and economy with due consideration of the objective condition and need of the country.

LEGAL STATUS OF THE CODE AND ITS IMPLEMENTATION

As per the definition of powers and duties of the executive organs of the federal democratic republic of Ethiopia proclamation No 691/2005, the Ethiopian building code of standard (EBCS) is prepared by ministry of works and urban development. And is implemented based on the Ethiopian building proclamation no. 624/2009 , council ministers of building regulation No. 243/2011¹² and ministry of works and urban development building regulation No.243/2003¹³.

Proclamation no. 624/2009 act No 34. States how the Structure should be designed:

1. Any building and any structural element or component thereof shall be designed to provide strength, stability, serviceability and durability in accordance with accepted principles of structural design. Such buildings may not exhibit signs of structural failure during their life span under normal loading.
2. Any building shall be designed and constructed in such a way that it shall not impair the integrity of any other building or property.

TYPES OF CODES

There are many cods but the relevant codes for this research are stated below:

- I. EBCS 1
- II. EBCS 2
- III. EBCS 2 part 2
- IV. e.t.c

ASSUMPTIONS OF THE CODE

In EBCS 2 section 1.1.8, "It has been assumed in the drafting of Ethiopian building code of standard(EBCS)that the design of concrete structures is entrusted to register structural or

¹² It doesn't describe the check list for structural design but expresses for Architectural, sanitary, and electrical

¹³ Presented in More detail manner than the two proclamations.

civil engineers, appropriately qualified and that the execution of the work is carried out under the direction of appropriately qualified supervisors.”

SLAB DESIGN IN EBCS

The slab analysis and design are put into two codes of EBCS, in which the actions (loads on slabs) are stated in EBCS 1 and the analysis and design including material property are included in EBCS 2. To have simple over view of the minimum requirement set by the codes, this study will asses of the codes separately and compare with well known codes¹⁴ ACI, EC, IS and BS and their difference with our code will be stated in footnotes of this research.

The two codes focus on design actions, safety and serviceability requirement of slab and other structures for the standard structural reliability.

ASSUMPTIONS ON EBCS

- a) Choices of structural system and the design of the structure is made by appropriately qualified and experienced personnel.
- b) Execution is carried out by personnel having the skill and experience
- c) Adequate supervision and quality control is provided during execution of the work, i.e in design office, factories and plants and on sites.
- d) The construction materials and products are used as specified in EBCS 1 or in EBCS 2 to 8 or in relevant supporting material or product specifications
- e) The structure will be adequately maintained.
- f) The structure will be adequately used (give service) based on the design assumption¹⁵.
- g) Design procedures are valid only when the requirements for the materials, execution and work man ship given in EBCs 2 to 8 are also complied with.

FUNDAMENTAL REQUIREMENTS OF DESIGN IN EBCS

A structure shall be designed to remain fit for the required function and sustain the actions which could occur during construction and use with appropriate degree of reliability and in an economy way during the intended life of the structure, to attain this it shall be given attention to structural safety and serviceability, including durability.

The structure shall also poses a capacity to with stand, events like fire, explosion, impact or consequence of human error to an extent disproportionate to the original cause. This can be fulfilled by avoiding hazards, selecting structure with low sensitivity to hazards, selecting suitable structural form to survive accident removal of individual element or limited part of the structure with acceptable localized damage, avoiding sudden catastrophic failure and increasing redundancy by tying structures together.

¹⁴ Codes

- I. ACI=American concrete institute
- II. EC= European code
- III. BS=British standard
- IV. IS=Indian standard

¹⁵ But in practice it very difficult to get buildings which serves for the function intended during design

The above requirements can also be made by the choice of suitable material, by appropriate design and detailing and with appropriate control during design construction and use.

To have good reliability, the design shall satisfy the measures stated below

- Serviceability requirement
- Representative value of action
- The choice of partial safety factors or appropriate quantity of design calculation
- Considering durability
- Structural integrity
- The accuracy of mechanical model
- The stringency of the detailing rules

In the design working life and durability to satisfy the function or purpose the building relevant design situation shall be selected (in this research) persistent situation (condition of normal use) will be considered with appropriate design life (50 years for buildings), the structure shall fit and durable for use throughout the design life with appropriate maintenance considering the environmental conditions at design stage with appropriate protection to material or product.

Table 7 Questioner and response

Respondents type	Question	Number of respondent	Response (%)		
			Y	N	NC
CE	10. Have you ever read all the codes in detail specially slab design and analysis?	10/10	40	40	20
CTE	5. Do you know the codes used for slab design?	3/3	66.7	33.3	0
ME	6. Have you ever implement the No. 624/2009 and 243/2011 proclamations in checking plans?	5/5	40	60	0
ME	7. Do you have in your office the Ethiopian Building code of standard (EBCS)?	5/5	40	40	20
ME	10. Do you use codes in slab design approval?	5/5	100	0	0
ME	27. On the proclamation no. 243/2011 recommends for tasks beyond the capacity of the building officer, he may procure the service of registered professional to perform specific task, have you ever use this act in practice?	5/5	0	100	0
	Then how do you check such conditions?	0/5	0	0	0
C3	4. Do you know the Ethiopian Building Proclamation No. 624/2009 and 243/2011?	18/18	61.1	38.9	0
C3	5. The benefits of the code is harmonizing of professional practice and ensure of appropriate level of safety, health and economy, do you think these benefits are on the ground?	18/18	16.7	66.7	16.7

C3	6. It has been assumed during drafting of the code, the design is performed by appropriately qualified registered structural or civil engineers, and construction is done based on appropriately qualified supervisors. Do you think this is actually happen?	18/18	22.2	66.7	11.1
C2	4. In EBCS 1 section 1.1.1(6) states for information not stated in EBCS can be used from euro code, have you refer euro codes, have you ever use euro codes as supporting cods?	14/15	46.7	40	6.7
C2	6. Do you think the code includes all the minimum possible information?	13/15	13.3	46.7	40
C2	9. Do you believe our codes are fully applied and implemented in day to day design?	10/15	6.7	20	40

Respondents type	Question	# of respondent	Response (%)				
			BS	EC	IS	ACI	NC
CE	16. Have you ever refer to other codes in slab design?	7/10	20	30	0	20	30

Respondents type	Question	# of respondent	Response (%)			
			easy	medium	complete	NC
C2	5. Do you think all the codes above are easily understandable?	15/15	20	80	0	0

Respondents type	Question	# of respondent	Response (%)		
			detailing	Luck of source of Table A.1	NC
C2	7. Which part of the code is Unclear or too complex to under stand	2/15	20	20	60

Due to the luck of availability of the code (40% respondent doesn't have the code in hand) about 40% of respondent never use the code for analysis and design of slabs. Moreover, 33.35% of respondents even didn't know which part of the code is used for analysis and design of slab, this clearly assure that the luck of availability of the codes. On the other hand majority municipal engineers never use proclamation 624/2009 and 243/2011 and never utilize the power the proclamation provide them (100% respondents never use such benefit).

Looking on the benefits of code preparation 66.7% contractor engineers agrees the benefits are not on the ground. Similarly, most the respondents (about 66.7%) believe majority of the designs are done by unqualified, unregistered engineers, hence it is clear that codes are not implemented in day to day design (only 6.7% say it is implemented). Those who use codes for analysis and design of slabs, more than half refers other codes (20% BS, 30% EC, and 20% ACI) for clarification and verification of unclear part (20% says it lacks detailing and 20% lack of reference and source for table A.1 of EBCS 2) of the document. But they never pass without underlining the code lack information (46.7% respondents) and can be said it easily understandable (80% say medium to understand).

ACTIONS IN EBCS

EBCS 1 classifies the actions based on their variability in time as, permanent action (dead load) (G), variable actions (imposed load) (Q) and accidental action (A), this actions are classified again based on category use of the building, such as area in dwellings, office, storages, industrial activities and roofs, etc. In permanent load, self weight of the slab, surface covering, non structural partition walls and linings, hand rails, safety barriers, parapets and curbs, wall cladding, suspended ceiling, insulation, fixed machinery, earth and ballast, cable trunking and conduits, are considered. Similarly in imposed load like, movable light weight partition, self weight of industrial equipment and occupants of the buildings,

CLASSIFICATION OF ACTION

i) Self weights

It is the weights of the permanent actions which depends on their geometric size and density of material in which these components are made. EBCS 1 gives densities of different construction materials and other densities are given in table 2.1 to 2.8. But it may be necessary to consider both the upper and lower characteristic value, of the self weight, When there is uncertainty about the precision of the value of self weights.

Self weight of floors and walls and partition

In EBCs section 2.5.3.2.1(1) to (4) states the self weight of partitions¹⁶, can be taken as equivalent distributed load and weight floor including of finishes (such as plaster and screed) and prefabricated wall finish and timber and other floor finish shall also be considered.

ii) Imposed loads

Those are loads arose from occupancy caused by normal use by persons, furniture and movable objects (example, light weights movable partition¹⁷, storage, the contents of

¹⁶ Partition loads as dead load, EBCS 1 and EC simply say partition can be assumed as uniformly distributed load; but for heavy partition the location and structural form of the slab are important and BS designates as permanent partition shall be assumed as dead load acting at particular location and size. IS doesn't state a thing about this. ACI only says wall is taken as dead load.

¹⁷ Light weight partition as imposed load

- In EBCS 1: light weight movable partition with no size descriptions.
- In EC: movable partition with limit in size,
 - for movable partitions with a self-weight 1.0 kN/m wall length: $q_k = 0.5 \text{ kN/m}^2$;
 - for movable partitions with a self-weight 2.0 kN/m wall length: $q_k = 0.8 \text{ kN/m}^2$;

containers), machine or vehicle and exceptional use such as exceptional concentration of persons or furniture, or moving or stacking of commodities which may occur during reorganizing or redecoration shall be considered. Imposed loads are modeled as uniformly distributed loads or concentrated load or combination of the loads.

Load arrangement of imposed loads

Concentrated loads shall not be applied with uniformly distributed load during analysis. If a building has single occupancy the imposed can be reduced according to the tributary area by a reduction factor of give by α_A as given in section 2.6.3.1.2

Imposed loads are classified based on different types of occupancy. These are residential, social, and commercial and administration areas which are categories in to 5 categories which are given in table 2.9 and table 2.10 of EBCS 1. Further, the code classifies the occupancy in two category, garage and traffic areas given in table 2.11 and table 2.12 (However this research doesn't consider slabs subject to machines & vehicles). Moreover, roofs are categorized in three parts as stated in table 2.14.

Table 8 Imposed load comparison of codes

Table. imposed load comparison of codes		Codes								
		EBCS 1			BS ¹⁸ 6399-1-1996			BS EC ¹⁹ 1991-1-1-1		
category	Subcategory	q _k (kN/m ²)	Q _k	unit	q _k (kN/m ²)	Q _k	unit	q _k (kN/m ²)	Q _k	Unit
A	General	2	2	kN	3	4.5	kN	2	3	kN
	Staircase	3	2	kN			kN	2	4	kN
	balcony	4	2	kN	4	1.5	kN/m ²⁰	4	3	kN
B ²¹	General	NG	NG	kN	4	4.5	kN	3	4.5	kN
	balcony				4	1.5	kN			
C	C1	3	4	kN	3	4.5	kN	3	4	kN
	C2	4	4	kN	4	3.6	kN	4	4	kN
	C3	5	4.9	kN	5	4.5	kN	5	7	kN
	Staircase				4	4	kN			
	balcony				4	1.5	kN/m			
	C4	5	4	kN	7.5	9	kN	5	7	kN
	C5	5	4	kN	7.5	4.5	kN	7.5	4.5	kN
D	D1	5	4	kN	4	3.6	kN	5	7	kN

- For movable partitions with a self-weight 3.0 kN/m wall length: $q_k = 1.2 \text{ kN/m}^2$.
- In ACI(light weight partition shall be assumed taken as uniformly distributed load the total partition load shall be greater than 0.7184 kN/m² but can be neglected is the live load greater than 3.84kN/m².
- In IS: light weight partition shall be assumed taken as uniformly distributed load which is 339% of the partition load run in kN/m, but the total partition load shall be in the range 1 to 1.5kN/m² and shall be less than or equal to 4kN/m run.
- In BS: This may be taken as a uniformly distributed load of not less than one third of the load per meter run of the finished partitions, For floors or offices, this additional uniformly distributed partition load should not be less than 1.0 kN/m².

¹⁸ This code describes the entire category in detail.

¹⁹ Takes ranges of loads for this category the maximum is taken.

²⁰ Line load at the edge of the balcony.

²¹ In EBCS 1 category B and D2 are not stated for what occupancy are belonged.

D2						5	7	kN
----	--	--	--	--	--	---	---	----

The color indicates the difference in value of imposed load from green color (the lowest value) to red color (the highest value) and similarity in the color indicates similarity in value. In some case EBCS 1 is similar to BS EC 1991-1-1-1 but varies as compared to BS 8110. Though, the code categorize building area as given in table 2.9 and classify in to A, B, C, D, E, with sub category for C, C1 to C5 and for D, D₁ & D₂, it doesn't clearly state category B and general description C and D₂. However, the code gives the amount of load for unclear category in table 2.10. This research is only limited to residential social, commercial and administration area (category of A to E) only.

In general though the code states the partition walls (except light weight movable partition) can be taken as permanent uniformly distrusted over the area, it doesn't give the size or the weight limit or the type of the partitions to assume as uniformly distributed load over the area or it doesn't put the method²² to tackle the partition load relatively heavier which are non structural.

Table 9 Questioner and response

Respondents type	Question	Number of respondent	Response (%)		
			Y	N	NC
CE	18. Do you know partition wall can be treated as imposed (live) load as per our code?	10/10	40	50	10

Respondents type	Question	# of respondent	Response (%)			
			Neglect	Take guesses	generally	NC
C2	10. In EBCS I there are five category of occupants but category B and D are not completely stated to which building function these belongs, how do you treat buildings not stated in the code?	10/15	0	6.7	20	40

The design actions stated in EBCS 1 of the code, live loads for category B and D are not clearly stated and about 40% of the responds are still unclear about the amount imposed loads on category B and D that they take should take in design and 20% generally take 3kN/m² and on other side 6.7% take guess. The other challenging and unclear on the code is

²² Even codes like ACI, EC, IS does not specify the method how to put or convert the load to uniformly distributed load over the area of slab.

partition load, accordingly 50% never Know light movable partitions shall be treated as live load.

SLAB DESIGN AS PER EBCS-2²³

In conjunction EBCS 1 this codes covers material property basis of design, analysis of plane elements, ultimate limit state, serviceability limit state and detailing provision.

MATERIAL PROPERTY

In research reinforced concrete is the target, hence, only concrete and steel are going to be covered as discussed on the limitation of this study.

CONCRETES

Concretes are classified in two as class I and II concrete. the class I are concretes which are carried out under the direction of appropriately qualified supervisors ensuring attainment of level of quality control found in EBCS 2 of quality control. Otherwise it class II.

In the code only 8 concrete grades are presented (C-5 to C-60)²⁴ in class I, and 3 grades in class II concrete (C-5 to C-20).

The code designation²⁵ for concrete grade is based on characteristic cube compressive strength of concrete (f_{cu}) of a cube specimen of size 150mm and it is approximately 1.25 of the characteristic cylindrical compressive strength of concrete (f_{yk}) of a specimen of size 150 diameter and 300m high.

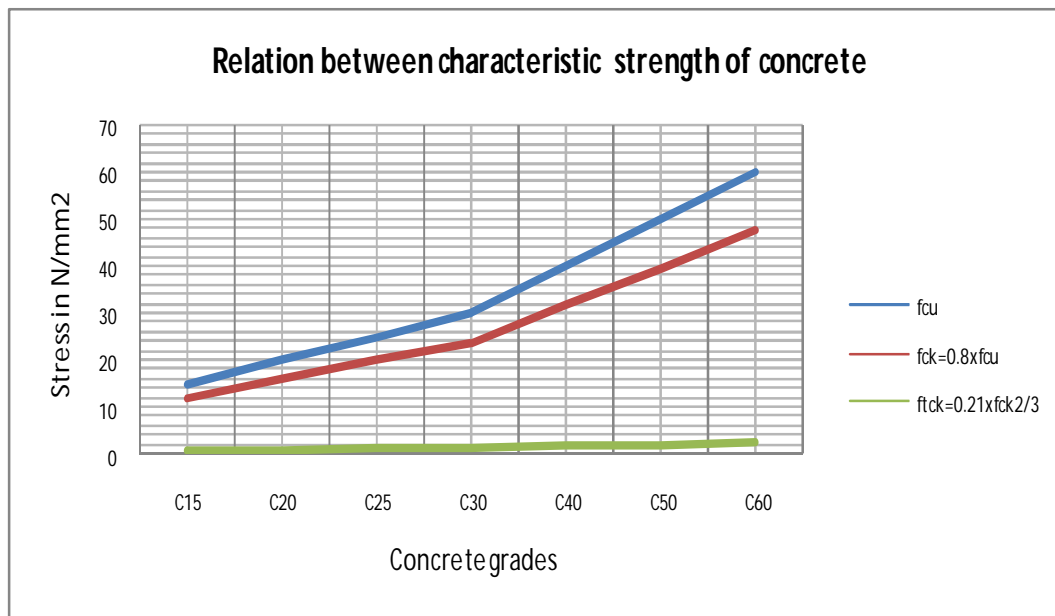


Figure 8 Relation between characteristic strength of concrete

²³ ACI318-08, BS8110-2, BS EC 1991-1-1-2000, IS 456 are have similar application.

²⁴ In ACI there is no designation for concrete, but these are classified based on their strength.

²⁵ Grade designation:

- In EBCS, IS and BS, the designation is based on the characteristic cube compressive strength, the only difference is IS takes M for concrete grade name.
- In EC, designation is based on the characteristic cylindrical compressive strength.

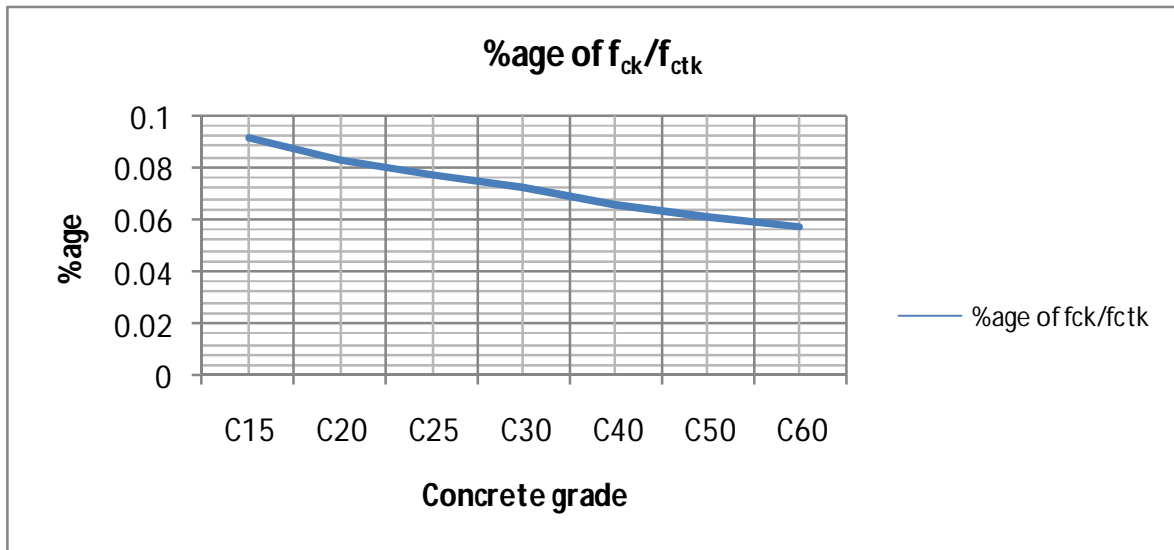


Figure 9 percentage of the ration f_{ck} to f_{ctk}

The characteristic tensile strength accounts 5 to 10 % of the pertinent characteristic cylindrical compression strength of concrete.

Generally, deformation property such as modulus of elasticity depends on grade of concrete, property of aggregate and mix design shall be determined on basis of laboratory tests especially from materials in use. If more accurate data are difficult to obtain, the code recommends formula considering characteristic cylindrical compressive strength and presented below comparing with different codes.

$$E_{cm} = 9.5(f_{ck} + 8)^{1/3},^{26} \quad (128)$$

This formula considers predominantly consists of quartzite gravel.

²⁶ Unlike the other codes EBCS and EC assumes the modulus of elasticity based on predominantly quartzite gravel, however, EC recommends reducing modulus of elasticity of aggregates like limestone and sand by 10% and 30% respectively, shall be increased by 20% for blast aggregate. Both of the codes give relatively larger value as compared to the other codes. It is clear the modulus of elasticity based on BS is the lowest value because it provides in range of value and average value is taken.

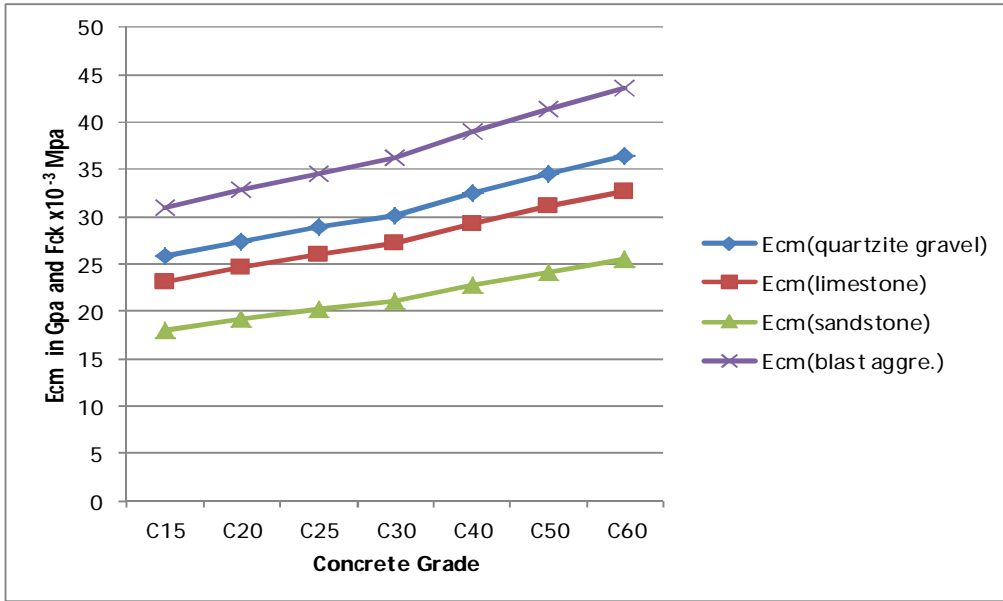


Figure 10 Modulus of elasticity for different types of aggregate²⁷.

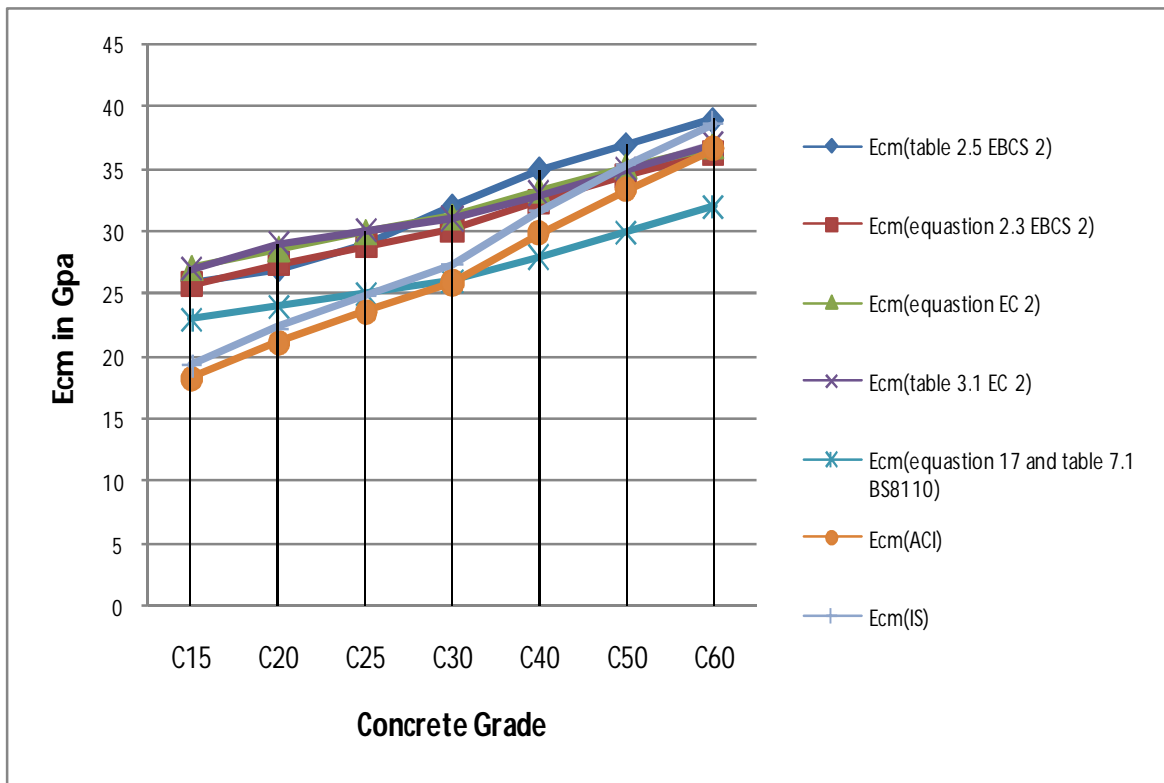


Figure 11 Modulus of elasticity on EBCS to other codes²⁸.

²⁷ Though further study is required but there are rumors that most strength test in Mekelle failed to get the pertinent strength, I think it may be this effect!!!

²⁸ The equations in EC and EBCS the E_{cm} are based on f_{ck} and BS and ACI are based f_{cu} . Unlike all the codes in IS, f_{ck} is designated for f_{cu} .

This graph shows the modulus of elasticity for concrete based on EBCS and EC are the highest, but unlike EBCS, EC reduces for aggregates other than quartzite gravel.

The Poisson's ratio²⁹ to consider lateral deformation can be taken any value between 0 and 0.2. The final creep of concrete³⁰($\phi_{(\infty, t_0)}$) which mainly depend on ambient humidity, dimension of the member, composition and maturity of concrete with size and duration of the load is given in table 2.6 of the code. Similarly the final shrinkage of concrete could affect by the environment and method and amount of curing is given in table 2.7 for plastic consistency range, and should multiply by 0.7 for stiff consistency.

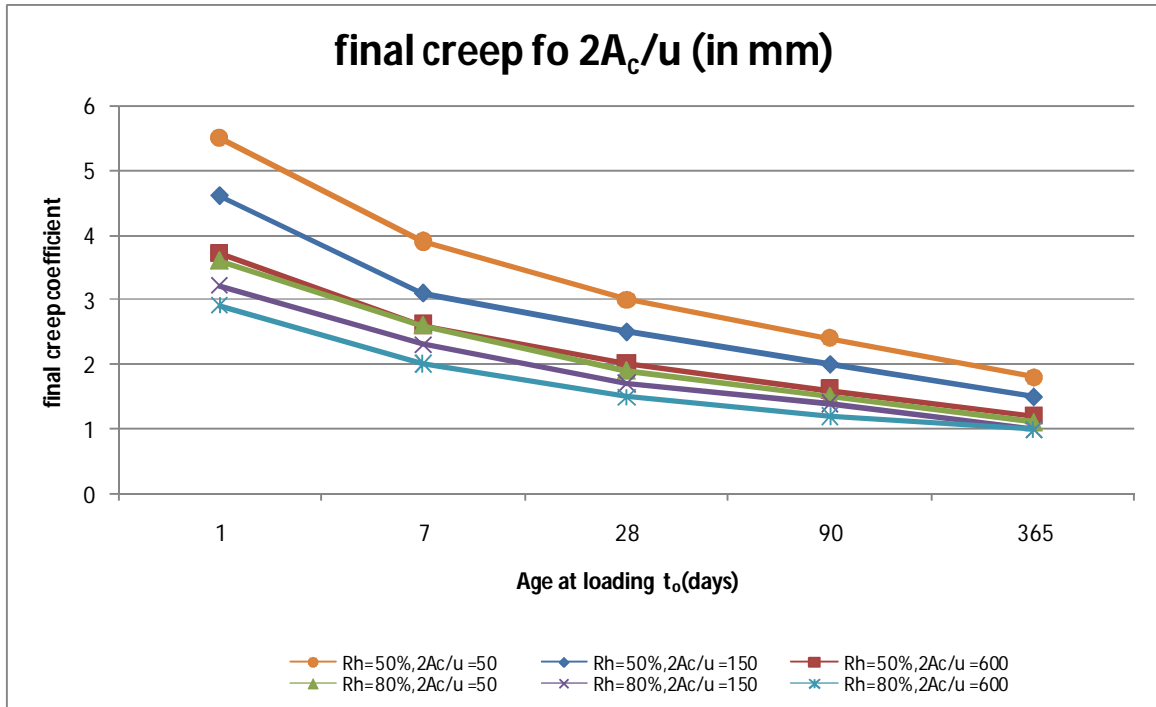


Figure 12 Final creep of concrete for different size of member and relative humidity and age.

The thermal expansion of concrete is proposed as 10×10^{-6} per $^{\circ}\text{C}$.

PROPERTY OF STEEL

Although, EBCS 2 doesn't specify the types of steel grades and the rang³¹ of steel grade at which the code is applicable, indirectly it included in EBCS part 2 design table 1a(S-300 to S-460). The code rather classifies the bars based on ductility (high ductility as class A and low ductility as class B) and surface shape of the bars (ribbed (deformed) and plain bars)and considers the density of steel as 7850 kg/m^3 and its thermal expansion is taken as 10×10^{-6} per $^{\circ}\text{C}$ with modulus of elasticity of steel of 200 Gpa.

²⁹ Poisson's ratio:

- In EBCS any number between 0 to 0.2
- In BS Poisson's ratio may be taken equal to 0.2 for un-cracked concrete and 0 for cracked concrete.

³⁰ IS recommends to neglect the effect of temperature, shrinkage and creep effect for ordinary buildings such as low rise dwellings whose lateral dimension doesn't exceed 45cm.

³¹ EC gives range of reinforcement grade 400 to 600 Mpa at code applicability, but the other property similar with EBCS.

Table 10 Questioner and response

Respondents type	Question	# of respondent	Response (%)				NC
			C20	C25	C30	Other	
CE	25. Which concrete grade do you mostly use for slabs in design?	9/10	10	70	10	0	10
CE	Why you select this grade for slabs	100% say Easily attainable quality					

Respondents type	Question	# of respondent	Response (%)			
			S300	S420	S500	Other
CE	26. Which steel grade do you mostly use for slabs in design?	9/10	80	10	10	0
CE	Why you select this grade for slabs	Easily available in market				
CE	27. The modulus of elasticity for concrete is only applicable to concrete made of aggregates predominantly composed of quartzite, do you modify it for other aggregate types such as limestone, sand and blast.	7/10	100% say they use same modulus of elasticity for all aggregate type			
CE	28. The code specifies the Poisson's ratio any number between 0 and 0.2 can be taken, what value is common in your slab design.	6/10	35% take 0.2 and 25% take between 0 and 0.2 and 40% never comment			
CE	29. Do you think Poisson's ratio have effect in one way slab reinforcement,	6/10	40% says "yes" and 20% say has no effect and 40% never comment			

Data collected from design reports and the questioner agree that most designers prefer C-25 for analysis and design of slabs (70% in questioner and 64.29% in design reports). Mostly say, because it easily attainable based on the country actual practice. Similarly steel S-300 grade is mostly used (80% in questioner and 92.86% in design report) for easily available in market. Irrespective of span 100% respondents take the same modulus of elasticity for all aggregate type. Though most respondents (35%) take Poisson's ratio of 0.2 and 25% take between 0 and 0.2, 20% doesn't know whether Poisson's ratio have an effect in slab particular in one way slab.

BASES OF DESIGN

The code considers a structure, or part of a structure is unfit for use when it exceeds a particular state i.e. the limit state within the criteria governing its performance (safety) and use (function and appearance). All the limit states are equally important to the structure and shall ensure adequate safety and serviceability. In this approach an element is designed

for the more critical limit state and check the remaining limit states whether satisfied or not to be reached.

The code covers two categories of limit state

- a) Ultimate limit state: a state prior to structural collapse or can be treated as collapse itself, in this part loss equilibrium, failure by excessive deformation, rupture, loss of stability are examples etc.
- b) The serviceability limit state: the state prior to the structure is no more serviceable. Which includes, deformations and deflections which cause bad appearance and damage to floor finish or other nonstructural elements. In addition, vibration creates discomfort and creep problem leads to poor durability.

DESIGN STRENGTHS

To satisfy the above limit states the design strength considering the uncertainty in material property, production and placing in addition to design uncertainty the code gives the design strength based on the partial factor of safety and is given by:

$$R_D \leq \frac{R_K}{\gamma_F} \quad (129)$$

For ultimate limit state the partial safety factors for class I and II are different and are given in table 3.1 of the code, which is $\gamma_c = 1.5$ for concrete and $\gamma_s = 1.15$ for steel for class I concrete and similarly 1.65 for concrete and 1.20 for steel for class II concrete.

Whereas unlike the ultimate limit state the partial safety factor of material is taken as 1 for both cases. It can be summarized that the design strength of concrete and steel with this formula.

$$f_d = \phi \frac{f_k}{\gamma},^{32} \quad (130)$$

Where concrete in compression $f_d = f_{cd}$, $f_k = f_{ck}$, $\phi = 0.85$, $\gamma = \gamma_c = 1.5$ and for concrete in tension $f_d = f_{ctd}$, $f_k = f_{ctk}$, $\phi = 1$, $\gamma = \gamma_c = 1.15$. Similarly for steel $f_d = f_{yd}$, $f_k = f_{yk}$, $\phi = 1$, $\gamma = \gamma_s$.

DESIGN LOAD AND COMBINATION

The variations in characteristic load may arise due to errors in design, construction in accuracies and possible unusual load increases, these scenarios are considered in Partial safety factor (γ_F) with the characteristic load which is given by

$$F_D \geq \gamma_F F_K \quad (131)$$

³² In BS: $f_{cd} = 0.45f_{cu}$, EC and EBCS: $f_{cd} = 0.4533f_{cu}$, IS: $f_{cd} = 0.447f_{ck}$ where f_{ck} means f_{cu}

Where g_F ³³ is given as 1.3 and 1.6 for dead load and imposed load of persistent design situation.

In building structures such as slab can be designed for loads combined as 1.3DL+1.6LL for ultimate limit state and 1DL+1LL for serviceability limit state.

Table 11 Questioner and response

Respondents type	Question	# of respondent	Response (%)
CE	31. What type of loading do you take for design?	8/10	50% use single loading case and 30% use different load cases and 20% never comment

The above table indicates ambiguity of loading considerations in slab design and analysis, that is about 50% respondents use single load case 1.3DL+1.6LL, on the contrast 30% say different load combination in slab design and analysis.

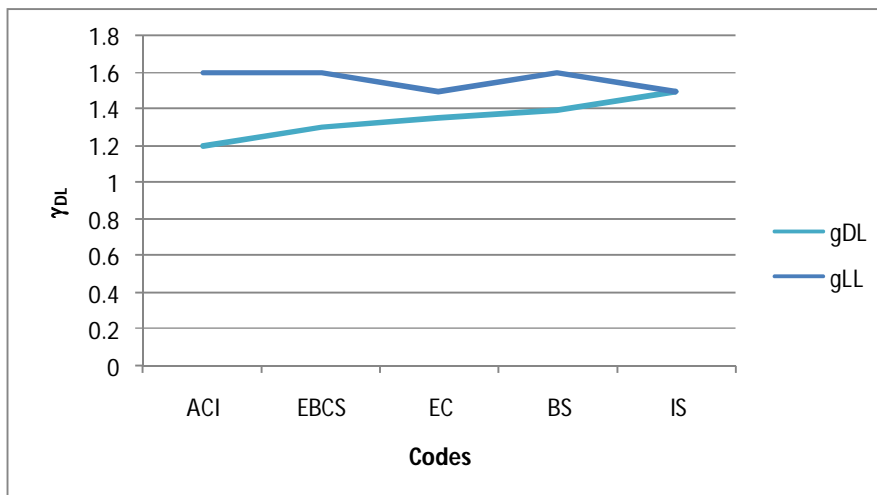


Figure 13 Load partial factor of safety of different codes

³³ g_F : load partial safety of factored

- EBCS: 1.3DL+1.6LL,
- BS: 1.4DL+1.6LL
- EC: 1.35DL+1.5LL
- IS: 1.5DL+1.5LL
- ACI: 1.2DL+1.6LL

ANALYSIS OF SLAB

CLASSIFICATION OF SLAB

The code classifies slabs as one way, ribbed slab and two ways and waffle slab and flat slabs based on their structural behavior.

ANALYSIS OF ONE WAY SLAB

Linear elastic method, plastic and non linear analysis for ultimate limit state and only elastic method for serviceability limit state are proposed for analysis of one way slab. The analysis of one way slab is carried out similar to beam of one meter width. This code doesn't specify any simplified method³⁴ of analysis for this type of slab.

CRITERIA FOR SLAB

EBCS 2 defines a structure to be treated as slab having side dimensions of a and d and thickness of h , the least side dimension shall be greater than 4^{35} times the thickness of the slab.

CRITERIA FOR ONE WAY SLAB

Either the slab is supported by two opposite and parallel sides of beams where the other two parallel sides are free of support or slab supported on four sides with the ratio of the longer span to shorter span is greater than 2^{36} .

MOMENT REDISTRIBUTIONS

The maximum moment redistribution allowed in the part one of code is 25%, on the contrary EBCS 2 part 2 states the maximum percent of redistribution is 30. The elastic linear analysis may be reduced by the reduction factor (δ) given in equation 3.13 of the code,

$$\delta = \begin{cases} k_1 + k_2 \left(\frac{x_u}{d} \right), & \text{for } \frac{l}{d} \leq 20 \text{ and continuous beam} \\ 0.75, & \text{for other continuous beam} \\ 0.9, & \text{for sway frames} \end{cases} \quad (132)$$

³⁴ Except EC and EBCS all give simplified analysis method for one way. Thought, the criteria to use this method varies to small extent from code to code.

³⁵ IN EC it 5 times the thickness

³⁶ All codes take the same criteria for classification of slab as one way which the ration of longer span to shorter span is greater than 2.

Table 12 Moment redistribution of different codes

Code	k_1	k_2	Maximum redistribution δ' (in %)
EBCS	0.44	1.25	25 ³⁷
BS ³⁸	0.4	1	20 ³⁹
EC	0.44	1.25	20 ⁴⁰
IS	0.6	1	30
ACI	$(1000\varepsilon_t)$ ⁴¹		20

Table 13 Span of depth ration of one way slabs

Span to effective depth ratio of one way slabs ⁴²				
Support condition	f_{yk}			
	300	400	460	500
Simply supported	24	20	18	17
End span	28	24	22	21
Interior span	33	28	26	24
Cantilevers	12	10	9	9

This table is based on the deflection equation 5.3 of EBCS 2. However, the equation doesn't specify up to what span is applicable.

The reduced moment can be calculated as $M_p = \delta M_e$

Moreover, to avoid catastrophic sudden failure of concrete crush and initiate extended ductile failure (tension control)⁴³ the section shall be under reinforced, to satisfy this code

³⁷ In EBCS 2 part 2 $\delta_{max} = 30\%$

³⁸ This applicable except at the support of cantilever, when Slabs amount of redistribution is unknown take a value of $\delta=15\%$ may be assumed for support moments and zero for span moments.

³⁹ IN BS(for Linear analysis and simplified methods) and IS (for Linear analysis and simplified methods) the criteria are

- Equilibrium between internal and external forces is maintained under all appropriate combinations of design ultimate load.
- Resistance moment at any section should be at least 70 % of moment at that section obtained from an elastic maximum moments diagram covering all appropriate combinations of design ultimate load for moment resisting frame less than G+4
- but 90 % for moment resisting frame greater than G+4

⁴⁰ In EC2 it is applicable continuous slabs which(for Linear analysis)

- are predominantly subject to flexure and
- have the ratio of the lengths of adjacent spans in the range of 0.5 to 2.0
- The moments at ULS calculated using a linear elastic analysis may be redistributed, provided that the resulting distribution of moments remains in equilibrium with the applied loads.

⁴¹ $\varepsilon_t \geq 0.002 + \varepsilon_y \geq 0.005$, for tension controlled

- This applicable for Except where approximate values for moments are used
- Redistribution of moments shall be made only when ε_t is equal to or greater than 0.0075 at the section at which moment is reduced.

⁴² IS gives l/d for span up to 10m and can be calculated for span greater than 10m by 10/span

limits the relative neutral axis depth of a section based on the amount of moment redistributions and is given in equation 9 of EBCS 2 part 2.

$$k_x = \frac{x}{d} = 0.8(\delta - 0.44) \quad (133)$$

Where

$$\delta = \frac{100 - \% \text{ of redistribution}}{100} \quad (134)$$

As discussed above the maximum redistribution is 25% hence the maximum redistribution moment reduction multiplier (δ) will be 75, and summarized as follows:

Table relative Neutral axis depth for different redistribution of moment as per EBCS at ULS⁴⁴

Table 14 relative Neutral axis depth for different redistribution of moment as per EBCS at ULS⁴⁵

%of redistribution	δ	k_x
0	100	0.448
10	90	0.368
20	80	0.288
25	75	0.248

ANALYSIS OF TWO WAY SLAB

CRITERIA FOR TWO WAY SLAB

Slab supported on four sides with the ratio of the longer span to shorter span is less than 2⁴⁶.

METHOD OF ANALYSIS

The code proposes linear analysis with or without moment redistribution, plastic analysis, and nonlinear analysis. But focuses only in the first two methods, the nonlinear method analysis⁴⁷ of slabs is not covered. The elastic linear analysis method is based on gross cross-section with Poisson's ratio⁴⁸ of between 0 and 0.2 and is applicable for both ultimate and

⁴³ EC, BS, EBCS does not state the tension strain at tension controlled design ϵ_t however ACI and BS the State of strain at this condition which is given as $\epsilon_t \geq 0.002 + \epsilon_y$

⁴⁴ $\epsilon_t = \epsilon_y + 0.002$ and $\epsilon_{cu} = 0.0035$

⁴⁵ $\epsilon_t = \epsilon_y + 0.002$ and $\epsilon_{cu} = 0.0035$

⁴⁶ All codes take the same criteria for classification of slab as two way which the ration of longer span to shorter span is less than or equal 2.

⁴⁷ It included and discussed only in EC 2 and BS

⁴⁸ Poisson's ratio

- In BS Where linear elastic analysis is appropriate; Poisson's ratio may be taken as 0.2.
- IN EC Poisson's ratio may be taken equal to 0.2 for un-cracked concrete and 0 for cracked concrete.
- IN ACI Poisson's ratio of concrete shall be permitted to be taken equal to zero.

serviceable limit states. Similar to the one way slabs, the maximum percent of redistribution of moment is 25%.

A linear elastic analysis (as said in EBCS 2 but not said in other cods and completely wrong) of slabs based on moment coefficient (which is rather derived from modified yield line as described below) is proposed in ANNEX A of EBCS 2⁴⁹. Redistribution is not allowed for this method and it is only applied to rectangular slabs.

ASSUMPTIONS

- a) Concentrated load (partition load) on one way slabs (EBCS sec A.3.1.(2))⁵⁰

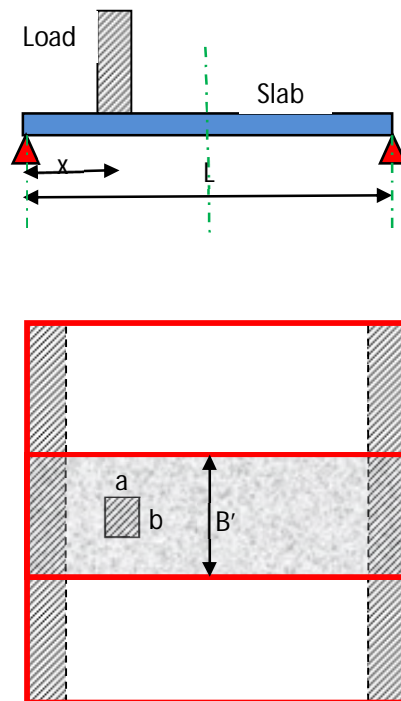


Figure 14 distribution of concentrated load on one way slabs

Effective width (B') carrying a concentrated load can be taken as (considering load width (b))

$$B' = b + 2.4 x \left(1 - \frac{x}{l}\right) / l$$

If the distance from the face of load to free end is less than 30% for the span of the slab which is under consideration.

- b) On two way slabs (EBCS sec A.3.1.(2))⁵¹

⁴⁹ This method is similar in BS, IS, and EBCS but EC2 doesn't state any method

⁵⁰ IS gives formula for cantilever slabs to distribute the concentrated load

⁵¹ IS gives formula for cantilever slabs to distribute the concentrated load

- i. The supporting wall or beams are assumed as unyielding⁵² and the minimum thickness of the supporting beam shall be as given in section A.3.1 (1) can given by;

$$h_1 \geq 2.5h_s \frac{l_1}{l_x} \quad (135)$$

$$h_2 \geq \begin{cases} 2.5h_s \frac{l_2}{l_y} \\ 2.5h_s \frac{l_2}{1.5l_x} \end{cases} \quad (136)$$

Where h_1 and l_1 the depth and clear span of the beam parallel to l_x , similarly h_2 and l_2 the depth and clear span of the beam parallel to l_y and h_s is the thickness of the slab.

This indicates the slab and the beam shall not deflect the same. But rather the slab shall deflect leaving the beam intact leads the beam will almost the entire shear come from loads and slab will not designed for shear only check is needed. On the contrast, if the beam is not unyielding (such as hidden beam in slab very common practice) it will be flexible and both slab and the beam could fail or deflect excessively. This violates the assumption considered during derivation of the methods (such as coefficient method, yield line method and strip method). The shear will be carried by both beam and slab which leads for further study.



⁵² This is only described in EBCS 2 apart from EC, BS and IS. however, Swedish and Canadian code also gives the depth of unyielding beam which is given bay

$D_b \geq \begin{cases} 2.5D_s \text{ for } r \leq 1.5 \\ 2.5rD_s \text{ for } r > 1.5 \end{cases}$, where $r = l_y/l_x$ and Canadian code gives $D_b = D_s(2l/b)^{1/3} = 1.26D_s(l/b)^{1/3}$

Figure 15 Visible (4cm) deflection due to small beam Depth.

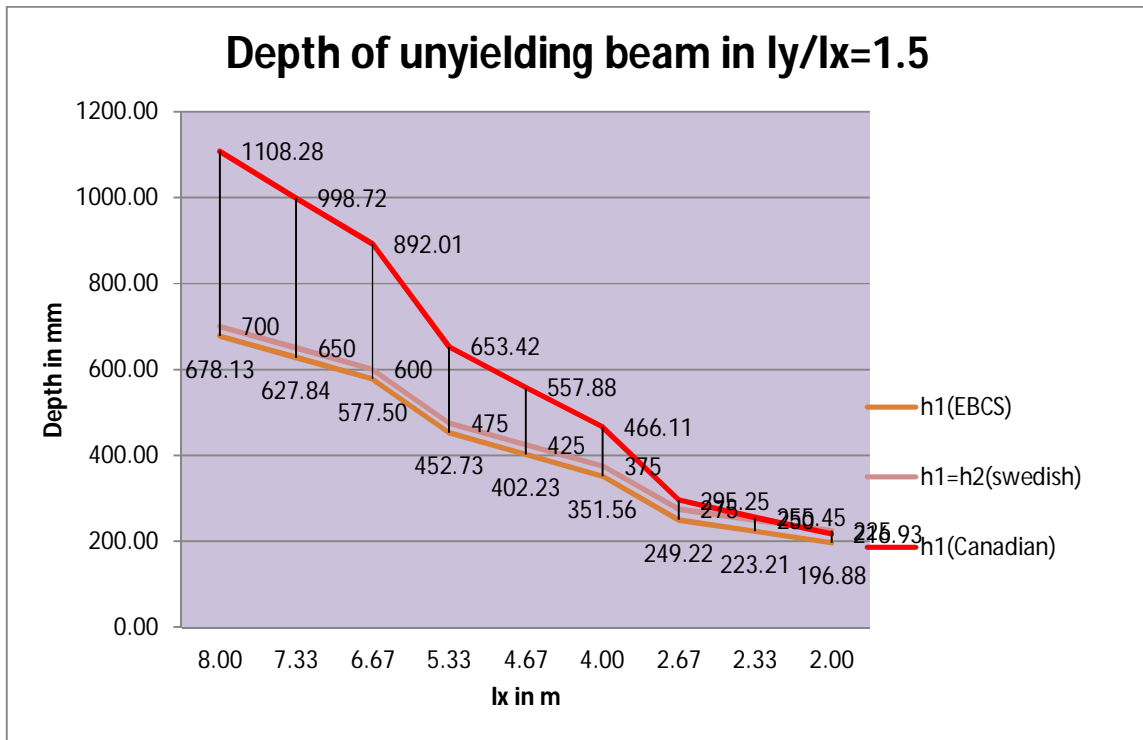


Figure 16 Depth of unyielding beam in $l_y/l_x=1.5$

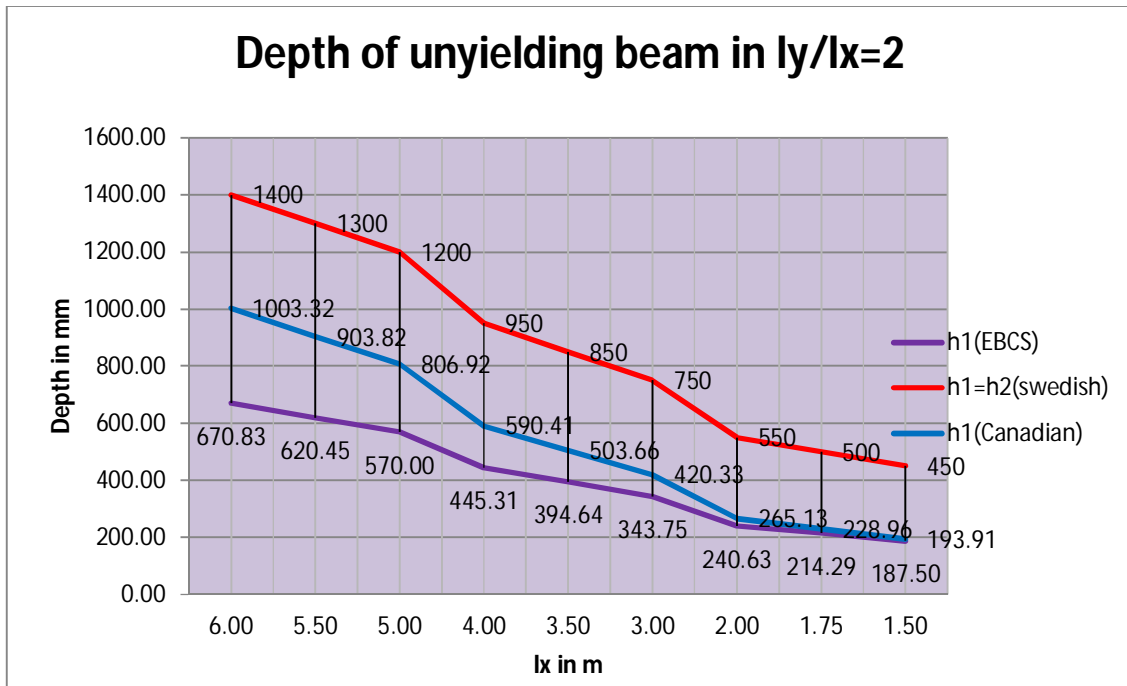


Figure 17 Depth of unyielding beam in $l_y/l_x=2$

In the above charts the depth for unyielding beam in EBCS is smaller as compare to Swedish and Canadian code⁵³. This is totally neglected in design and mostly deflections are visible during stripping of form work, but latter they fill it using plastering and cement screed. Moreover, in most cases terrazzo spall away special at the center and at periphery of the slab due to excessive deflection of slab as shown in the photo, practically 4cm deflection is observed in a slab of 4 by 8m slab with beam depth of 500mm. where from fig. 50 above the depth of unyielding beam was estimated 445.31mm in EBCS, 590.41mm in Swedish code and 950mm in Canadian code, which indicates EBCS 2 underestimates the depth of the beam and the deflection might increase if the depth were used based on EBCS equation .but however further study is needed to see the shear participation of the slab and beam.

- ii. The slab load shall be uniformly distributed over the area; even partition load, if these meets the criteria set in section A.3.1 (2) of the code. The point or line load shall converted to equivalent uniformly distributed load using approximate rules⁵⁴ provided that

$$F_{D(partition)} \leq 0.2F_{(DL(including\ partition)+LL)} \quad 55 \quad (137)$$

To verify this, a sample slab of 6m by 7m is taken and with HCB partition walls of 20cm and 15cm thick and 3m high is taken as shown in the figure. The analysis is done by yield line method using virtual work method. It is done by varying the partition wall and live load for two cases.

· Slab depth	15.00
· Live load	5.00
· L_x	6
· L_y	7
· Concrete grade	C-25
· Steel grade	S-300
· Assume isotropic reinforcement in both direction	
· 45° yield line bisects the slab	

⁵³ This also applicable to elastic, yield line and strip method and shall be compared with equation v equation 5.3 and the larger shall be taken.

⁵⁴ There are many simplified approximate analysis methods for partition wall. These methods varies from the simplest, which accounts the partition wall load by taking additional 20% of the slab panel weight, to an empirical formulae given by many researcher around the world. In this study we will consider two of them, Swedish method and Reynolds method, because of their wide application. Even the other codes do not state any approximated method. the problem in EBCS is it does not either express the limitation for light moving partition or it doesn't classify the partition load as live and dead load for the load less than 20% of the total load.

⁵⁵ This does not express either the loads should be factored or un-factored

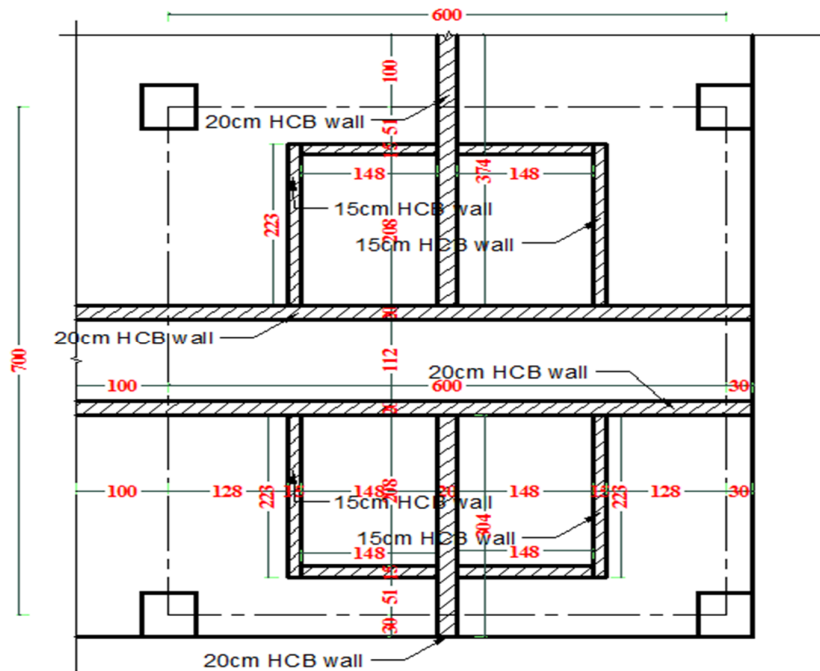


Figure 18 Sample slab plan and design data

- a) Actual Line load is placed in its location and analyzed using virtual work of yield line method.
- b) The total wall load is distributed over the area

The spread sheet used for analysis is developed based on virtual work method (yield line method). And it is presented in annex B and the results are summarized as follows.

Table 15 partition load analysis and comparison.

Live load (kN/m ²)	Loading				m (kNm)			m' (kNm)		
	Wall (LL) (kN/m ²)	Total excluding wall (TEW) (kN/m ²)	Total (kN/m ²)	% WL to TL(TEW + LL) (kN/m ²)	Case "a"	Case "b"	% error	Case "a"	Case "b"	% error
2	12.06	10.24	22.30	54%	25.33	24.79	2.141%	33.78	33.06	2.141%
	11.05	10.24	21.29	52%	24.42	23.86	2.276%	32.56	31.82	2.276%
	9.26	10.24	19.50	47%	23.41	22.88	2.262%	31.21	30.50	2.262%
	8.42	10.24	18.66	45%	22.29	21.36	4.202%	29.72	28.47	4.202%
	4.02	10.24	14.26	28%	15.89	14.95	5.927%	21.19	19.94	5.927%
	0.00	10.24	10.24	0%	10.63	10.63	0.000%	14.18	14.18	0.000%

3	12.06	11.84	23.90	50%	26.66	26.77	-0.391%	35.55	35.69	-0.391%
	11.05	11.84	22.89	48%	25.75	25.83	-0.301%	34.33	34.44	-0.301%
	9.26	11.84	21.10	44%	24.74	24.92	-0.734%	32.98	33.22	-0.734%
	8.42	11.84	20.26	42%	23.62	23.27	1.501%	31.50	31.02	1.501%
	4.02	11.84	15.86	25%	17.22	16.43	4.582%	22.96	21.91	4.582%
	0.00	11.84	11.84	0%	11.96	11.96	0.000%	15.95	15.95	0.000%
4	12.06	11.84	23.90	50%	26.66	26.77	-0.391%	35.55	35.69	-0.391%
	11.05	11.84	22.89	48%	25.75	25.83	-0.301%	34.33	34.44	-0.301%
	9.26	11.84	21.10	44%	24.74	24.92	-0.734%	32.98	33.22	-0.734%
	8.42	11.84	20.26	42%	23.62	23.27	1.501%	31.50	31.02	1.501%
	4.02	11.84	15.86	25%	17.22	16.43	4.582%	22.96	21.91	4.582%
	0.00	11.84	11.84	0%	11.96	11.96	0.000%	15.95	15.95	0.000%
5	12.06	15.04	27.10	45%	29.32	30.72	-4.766%	39.10	40.96	-4.766%
	11.05	15.04	26.09	42%	28.41	29.75	-4.732%	37.88	39.67	-4.732%
	9.26	15.04	24.30	38%	27.39	29.00	-5.855%	36.53	38.67	-5.855%
	8.42	15.04	23.46	36%	26.28	27.09	-3.081%	35.04	36.12	-3.081%
	4.02	15.04	19.06	21%	19.88	19.40	2.432%	26.51	25.86	2.432%
	0.00	15.04	15.04	0%	14.62	14.62	0.000%	19.49	19.49	0.000%

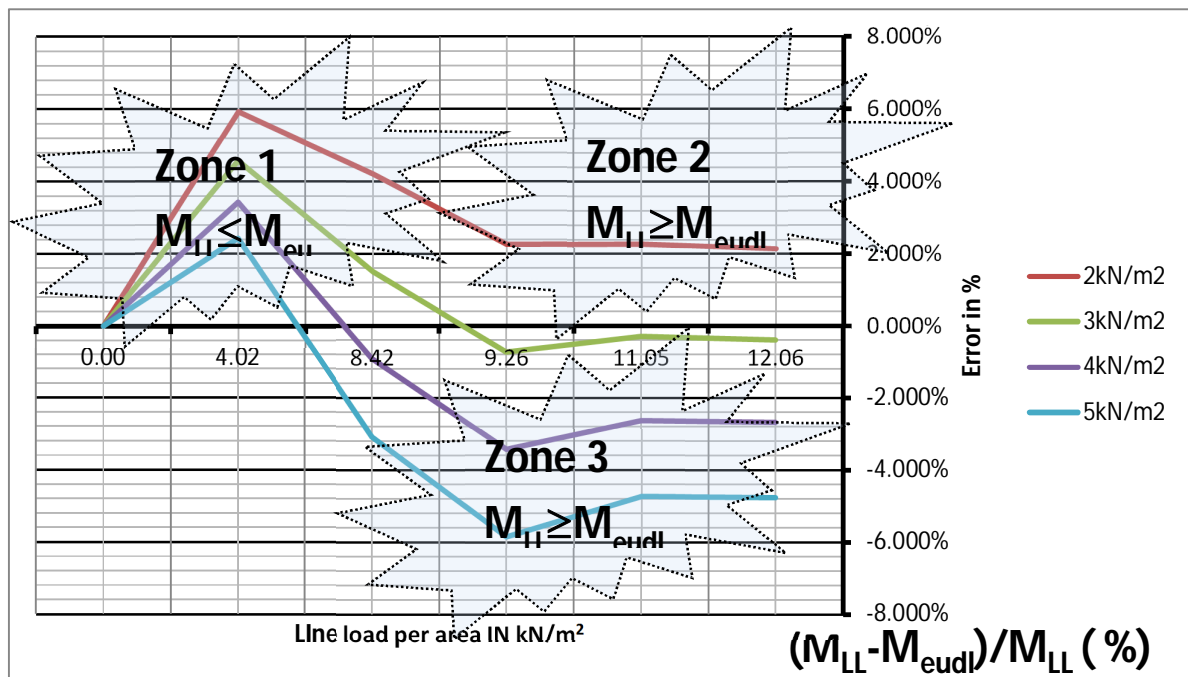


Figure 19 Sample slab plan and design data

The graph above shows the error of bending moment due to replacing the line load (wall load) with equivalent uniformly distributed load.

$$w_{eudl} = \sum w_{ll} / A$$

$$w_{Total} = 1.3w_{eudl} + w_{1.3DL+1.6LL}$$

$$Error(\%) = (M_{LL} - M_{eudl}) / M_{eudl}$$

Hence, the graph shows three Zones for this particular example (the worst case support condition in order to exaggerate the result)

Zone1:- Wall load is very small which accounts 0 to 28 % of the total load, indicates the estimation line load by simple equivalent uniform distributed load gives bit higher result(0 to 6 %) as compare to actual line load. In this Zone the error at wall load of 4.02 kN/m² , the error is higher for smaller live load. Here the assumption safe but uneconomical.

Zone2:- Wall load is medium to high which accounts greater than 28 % and live is 2 kN/m², hence, the error is in the safe side, relatively economical as compared to Zone 1.

Zone3:- Wall load is medium to high which accounts greater than 28 % and live is 3 to 5 kN/m², hence, the error is in the un-safe side(i.e. the equivalent uniformly distributed load underestimates the moment 0 to 6% , as the live load becomes higher the estimation will gain larger error. Hence, work method of wall load as line load shall be used.

Table 16 Questioner and Response

Respondents type	Question	# of respondent	Response (%)
CE	24. How do you consider partitions in one way slab?	9/10	40 % As equivalent distributed load 20% Add as dead load,(20% of the total load) 10% Use approximate methods such as, Use as concentrated load 20% No comment

Though, 40% of the responds the same procedure, they may be safe in lower live load and unsafe in higher live loaded buildings and Some engineers take partition wall mostly commonly 1.5 to 3kN/m² for all categories of buildings function, and some (20% of respondents) take 20% of the total load, which these logically under estimate the actual partition load moment specially for wall loads greater than 28% of the total load.

INDIVIDUAL PANEL MOMENT

The bending moment of each panel can be computed as follows:

$$m_i = \alpha_i (g_d + q_d) l_x^2 \quad (138)$$

Where α_i can be taken from table A.1 (found in ANNEX _____ of this research) or compute using equation A.2 to A.4 of the code. The α_i from table A.1 and equation is similar except insignificant difference in some cases which can be neglected.

$$\alpha_{yf} = (24 + 2n_d + 1.5n_d^2) \times 10^{-3} \quad (139)$$

$$\alpha_{xf} = \beta (\sqrt{1 + r_3} + \sqrt{1 + r_4})^{-2} \quad (140)$$

$$\beta = \frac{2}{3 \left\{ 1 - (l_y/l_x)^{-1} \sqrt{2\alpha_{xf} (\sqrt{1 + r_1} + \sqrt{1 + r_2})} \right\}} \quad (141)$$

Where n_d is the number of discontinuity ($0 \leq n_d \leq 4$), r_1, r_2, r_3, r_4 are the ration of negative moment to positive moment taken as $4/3$ for continuous edge and 0 for discontinuous edge.

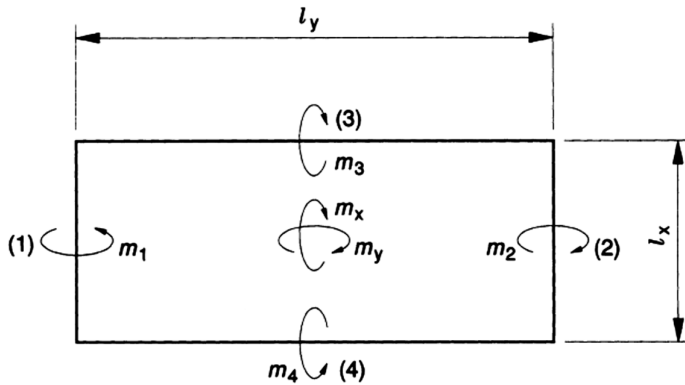


Figure 20 Explanation of the derivation of the coefficient of Table A-1

m_1, m_2 , are M_{ys} and m_3, m_4 , are M_{xs} and m_x, m_y , are M_{xf} and M_{yf} respectively which indicate the moments per unit width in the directions indicated and are given by α_i etc. multiplied by $(g_d + q_d) l_x^2$.

These moments are applied to the middle strip only which accounts $\left(\frac{3}{4}l\right)^{56}$ and shall be detailed as per sec. 7.1.7 of the code, however, for edge strip which is $\frac{l}{8}$ minimum reinforcement is provided as per sec 7.2.2.2.

⁵⁶ $l = l_x$ and $l = l_y$ for the short and long sides of the slab respectively.

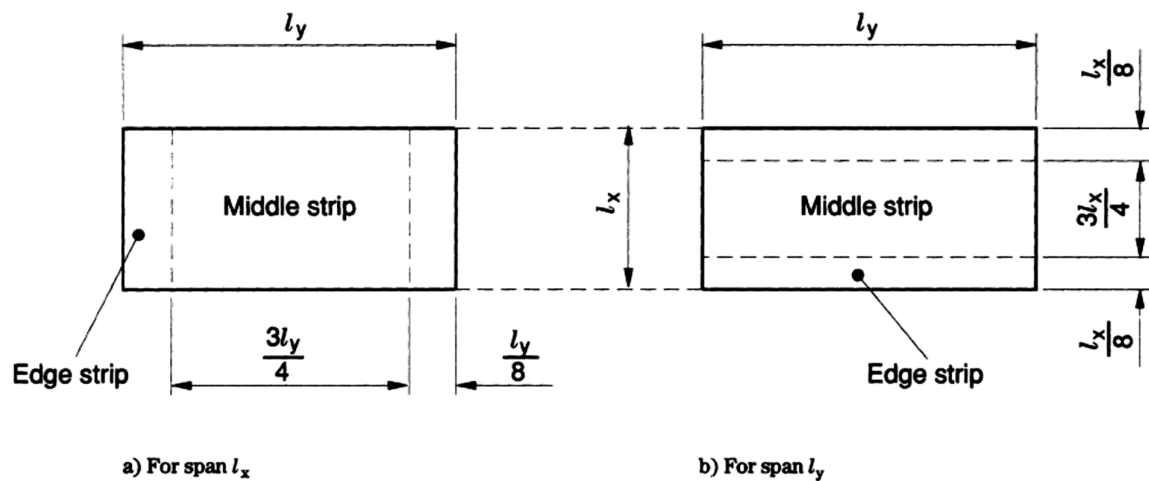


Figure 21 Division of slab into middle and edge strips

The moment in continuous⁵⁷ slab can be treated either in method I or method II based on the support moment difference.

If the initial support moment of slab difference is less than 20%⁵⁸ and the ratio of live load to permanent load is less than 2.5 and 0.8 for internal and external structure respectively method I is used. Other than this method II is used. In method I the design can be performed either using initial moment directly or based on average initial moment at the support, hence the later is economical.

In method II the moment difference is distributed by moment distribution method of analysis and the span moment are adjusted or increased by the factor (in table A-2) times the support moment difference.

In general, The bending moment of sides with partial fixity⁵⁹ can be calculated based on ratio of length fixed part to length of simply supported and the bending moment will be computed by interpolating of the different support conditions.

WHERE DOES THIS METHOD COME FROM?

Although it is clear that it is directly taken from British code with some modifications in assumption, it is hard to accept these assumption modifications without knowing the source of this method. Moreover, the British code doesn't specify where method is derived neither in Indian and in euro codes, but some literature and books say, it is based on modified yield line analysis. These books are reinforced concrete designer's handbook 10th edition by Reynolds & Steedman page 180, design of reinforced concrete structures by M.L. Gambir page 130 and Reinforced Concrete Design by Pillai & Menon page 434. Since moment redistribution is not permitted in this method (which is completely inelastic

⁵⁷ In EBCS it is somewhat complex procedure, in the contrast BS and IS provide similar procedure and simple in application and interpretations

⁵⁸ 20% difference is not expressed in BS and IS only say if the moment difference is significant.

⁵⁹ This not expressed in ACI, BS, EC and IS

analysis), all the above writers argued that the support moment difference shall not be done based on moment distribution (completely based on elastic analysis) rather, the maximum moment shall be taken for design and the bar length in the span where moment is increased shall be extended farther beyond the inflection point for the new negative bending moment. Moreover, those say no moment adjustments shall also be done to span moments. The figure below shows charts based on yield line analysis where BS and EBCS are derived. This can be verified using yield formulas (shown in table below) considering the assumption stated in EBCS.

Assumptions

- The bottom steel in either direction is uniformly distributed over the 'middle strip' which spreads over 75 percent of the span;
- The 'edge strip' lies on either side of the middle strip, and has a width equal to $l_x/8$ or $l_y/8$ top steel is provided in the edge strip adjoining a continuous edge (and at right angles to the edge) such that the corresponding flexural strength (ultimate 'negative' moment capacity) is $4/3$ times the corresponding ultimate 'positive' moment capacity due to the bottom steel provided in the middle strip in the direction under consideration;
- The corner reinforcement provided is sufficient to prevent the formation of 'corner levers', i.e., forking of diagonal yield lines near the corners.

Table 18 Comparison between table A.1 and Yield line method

Method	Short direction	
	+ve moment coefficient	-ve moment coefficient
EBCS	0.047	0.063
Yield line formula	0.049	0.066
% difference	-4%	-5%

The maximum difference is 5%, this is due to the length of yield line assumed in the first method, that is $l=0.75l_x$ as given in EBCS 2 and similarly for l_y , but in yield line formula (particularly for this case only) it uses $l=l_x$.

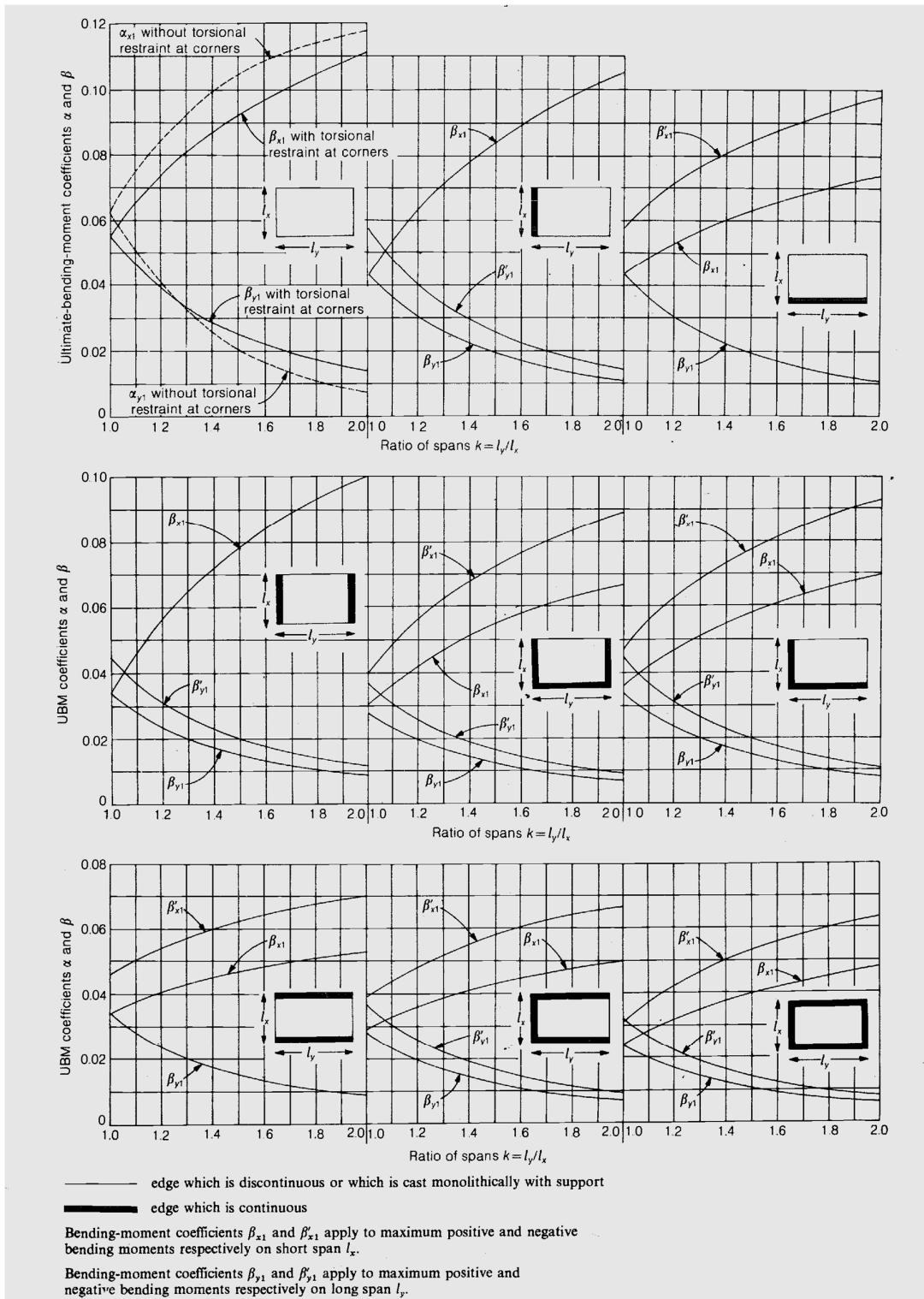


Figure 22 Moment coefficient of uniformly loaded rectangular slab (BS and EBCS requirement)⁶⁰

⁶⁰ In the above chart the coefficient of positive moment in the long span decreases as l_y/l_x increases but BS and EBCS take constant value for all l_y/l_x .

IS THIS METHOD REALLY CONSERVATIVE

Most engineers say this method is conservative considering the assumption put only in EBCS 2 which categorizes this method as elastic analysis. But this is not true, practically as described above the method is completely derived from plastic analysis particularly yield line, it is known yield line is upper bound that is mathematical correct but unsafe or on the virtue failure if little addition load is increased.

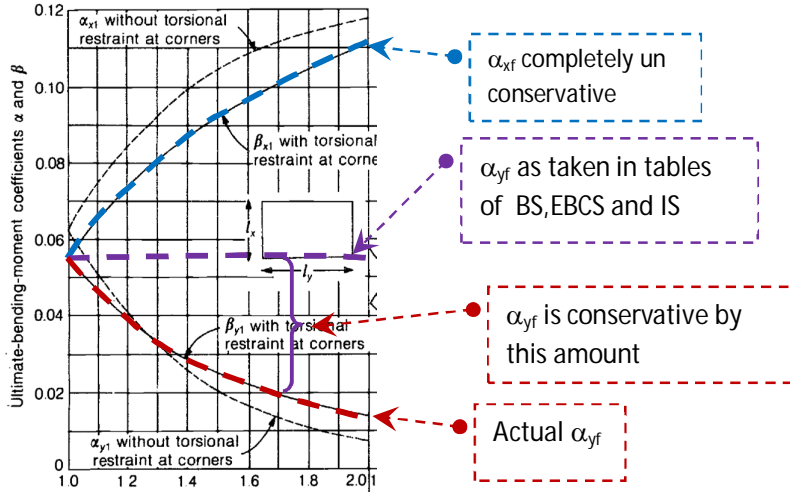


Figure 23 Modified yield line chart which is base of EBCS method

Taking simply supported rectangular slab supported on four sides (corners are held down) subjected to load of $g_k=4\text{kN/m}^2$ and $q_k=6\text{kN/m}^2$. let see by how much is α_{yf} from EBCS table is conservative than the actual α_{yf} and compared it to elastic analysis method derived by grashof and Rankine given in the table found in reinforced concrete designer's hand book 10th edition by Reynolds & stedman.

Table 19 Comparison of elastic analysis to EBCS method and modified yield line method presented in chart form.

			Grashof and Rankine		EBCS		Actual graph	
l_x	l_y	L_x/l_y	α_{x3}	α_{y3}	α_{xf}	α_{yf}	α_{xf}	α_{yf}
5	6	1.2	0.418	0.202	0.074	0.056	0.074	0.04
3	5.1	1.7	0.622	0.08	0.101	0.056	0.101	0.02

Grashof and Rankine		EBCS		Actual graph	
m_{xf}	m_{yf}	m_{xf}	m_{yf}	m_{xf}	m_{yf}
$=\alpha_{x3} \times (1/8) \times 10 \times 5^2$	$=\alpha_{y3} \times (1/8) \times 10 \times 6^2$	$=(\alpha_{xf} \text{ or } \alpha_{yf}) \times 10 \times 5^2$			

			Grashof and Rankine		EBCS		Actual graph		
I_x	I_y	L_x/I_y	α_{x3}	α_{y3}	$\alpha_{xf,EBCS}$	$\alpha_{yf,EBCS}$	$\alpha_{xf,ACT}$	$\alpha_{yf,ACT}$	
5	6	1.2	19.855	13.816	18.5	14	18.5	10	
3	5.1	1.7	29.545	5.472	25.25	14	25.25	5	

As seen from table above the moment in shorter span the elastic moments are higher (7 to 15%) than moment calculated using the chart above and based on EBCS table. Similarly the moment calculated in the longer direction, the elastic moment is higher (by 9 to 28%) than moment calculated using the chart above. But the elastic moment in the longer span is lesser than EBCS (1% for $I_y/I_x=1.2$ and 61% for $I_y/I_x=1.75$). We can say EBCS is un-conservative in the shorter span for all I_y/I_x and the error becomes higher as I_y/I_x goes higher. On the contrast EBCS table gives conservative result which is the advantage goes higher as I_y/I_x become larger.

PLASTIC ANALYSIS

EBCS 2 recommends two method of plastic analysis for ultimate limit state check; these are yield line and strip method based on conditions⁶¹ stated below.

- The area of tensile reinforcement shall not exceed, at any point or in any direction a value to $\frac{x_u}{d} = 0.25$
- If the static method is used, the moment distribution selected shall not differ substantially from the elastic moment distribution.
- If dynamic method is used, the ratio of the moments at intermediate supports to the moments in the span should be between 0.5 and 2.0

Table 20 Questioner and Response

Respondents type	Question	# of respondent	Response (%)
CE	19. Which slab type is commonly designed by your office?	6/10	10% design one way, two way slabs and ribbed slab, 20% design all except waffle, 20% design two way slab only and 10% both one, two way but 40% never comment
CE	20. Which one of these of one way slab types was used?	7/10	30% design Slab supported by two parallel side beams and the two parallel sides are free. 10% design Slab supported by four beams but the length ratio of larger side to shortest side greater than 2 60% leave it blank

⁶¹ The conditions stated in EBCS are particular, but in EC the conditions are applicable for both plastic methods. Whereas BS it doesn't put any conditions but states, "Johansen's yield line method or Hillerborg's strip method may be used provided the ratio between support and span moments are similar to those obtained by the use of the elastic theory".

Respondents type	Question	Number of respondent	Response (%)		
			Y	N	NC
ME	18. Do most consultants have similar method of analysis and design and detailing of slab?	5/5	40	60	0
ME	21. Do you have a chance to approve and check slabs analyzed by finite element software?	5/5	40	40	20
ME	23. Some engineers take slab moment from SAP or ETABS moment counter, do you think this write?	5/5	60	40	0

The most commonly designed slabs are two way slabs, one way and ribbed slabs are also designed by 10% for respondents, but no one designs waffle slab. ANNEX A part of EBCS 2 states the way of applying partition load in slabs which are designed as per the table A.1, hence 40 % of designers treat heavy partition loads as equivalent distributed load and 20% took as additional dead load (20% of the total load) and 10% use approximate method. For this reason most consultants have no similar design methods or packages (as responded by 60% of the municipal engineers). In conjunction to table A.1 of EBCS almost 50% of designers use finite element method based packages which are not included in our code. And 60% use moment form SAP and ETABS software to design a slab.

SLAB DESIGN

Both one way and two way slabs are designed as beam of width 1m for ultimate limit state which is the critical one based on the code. The analysis of the section based on ultimate limit state assumes:

- Plane section remains plane.
- The strain of the concrete and steel the same at particular location.
- The tensile strength of concrete is neglected.
- The ultimate strain of concrete is 0.0035^{62} for simple and compound and 0.002 in axial compression.
- The ultimate strain of steel is 0.01

DUCTILITY REQUIREMENT OF THE SECTION

The part 2 of the code gives the limit for ductility which avoids sudden catastrophic concrete crush failure. It is based on the relative neutral axis depth limit, which is $\frac{x}{d} = 0.448^{63}$ for no

⁶² In ACI it 0.003

⁶³ x/d limit

- 0.5 in BS for and 0.448 in EC and EBCS for all steel grades.
- In ACI and IS it is based on steel grade, different x/d for different grade.

moment redistribution. To satisfy this and considering the strain distribution in EBCS 2 figure 4.1 slab design falls in Zone 3. Based on the assumption on the code section 2.6(2) the characteristic strength f_{yk} is $f_{0.2}$ the strain offset (proof strain) is 0.002 there for the ductile strain of the steel can be computed as $\epsilon_t = \epsilon_y + 0.002$.

Table 21 Ductility property of steel

Ductility property of steel						
Grade	f_{yk}	ϵ_y	$\epsilon_y+0.002$	$(x/d)_{max}$	$(x/d)_{min}$	$(\rho/\rho_b)_{max}$
S300	300	0.0013	0.0033	0.514	0.259	0.71
S400	400	0.0017	0.0037	0.483	0.259	0.72
S460	460	0.0020	0.0040	0.467	0.259	0.73
S500	500	0.0022	0.0042	0.456	0.259	0.74
fy=531.6	531.6	0.0023	0.0043	0.448	0.259	0.74

There for the max steel ratio $\rho_{max} = 0.74\rho_b$ ⁶⁴ for $\frac{x}{d} = 0.448$

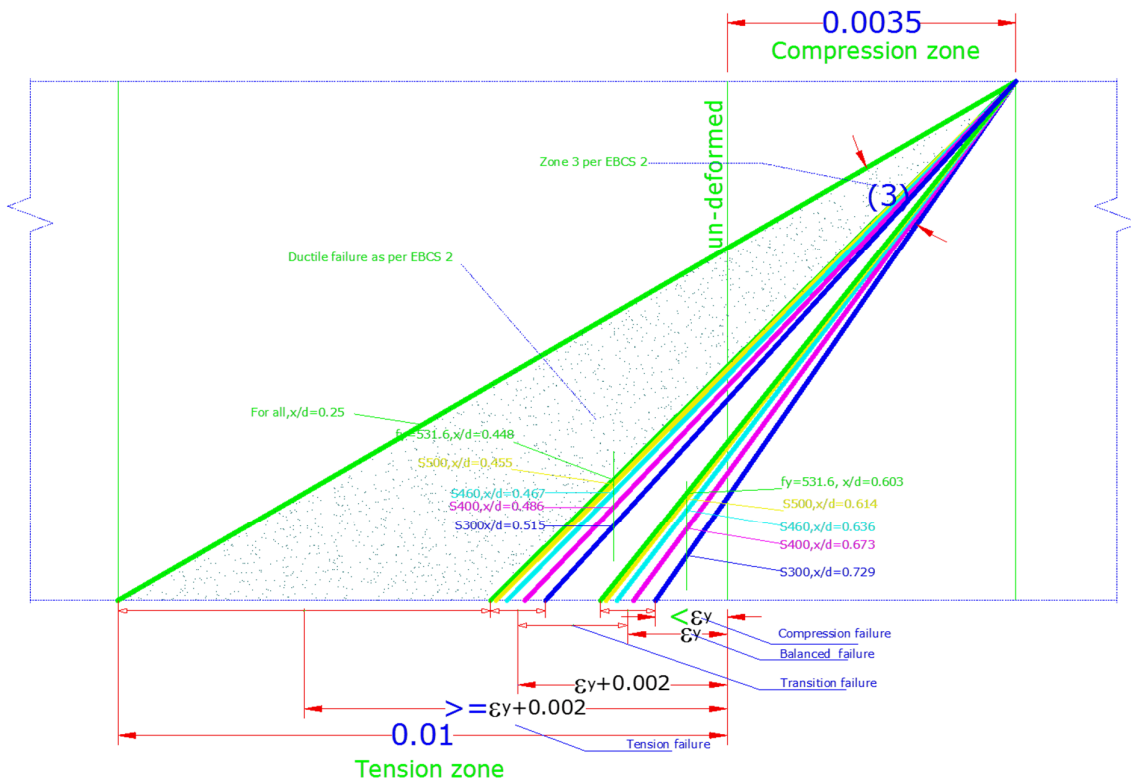


Figure 24 strain diagram in ultimate limit state for different grades of steel

For $\epsilon_s \geq \epsilon_y$ the relative neutral axis depth can be computed from the similarity triangle for figure above which is given by

⁶⁴ In ACI it $\rho_{max} = 0.75\rho_b$

$$\frac{x}{d} = \frac{0.0035}{0.0035 + \varepsilon_y + 0.002^{65}} = \frac{0.0035}{0.0055 + \varepsilon_y} \quad (142)$$

As you can see from figure above the steel grades S300 to S500 already yields before the relative neutral axis depth of 0.448 as per the code, this corresponds to $0.74\rho_b$.

Table 22 strain ε_t for different moment redistribution

δ'	(x/d)	ε_t
0	0.448	0.0043
10	0.368	0.0060
15	0.328	0.0072
20	0.288	0.0087
25	0.248	0.0106
30	0.208	0.0133

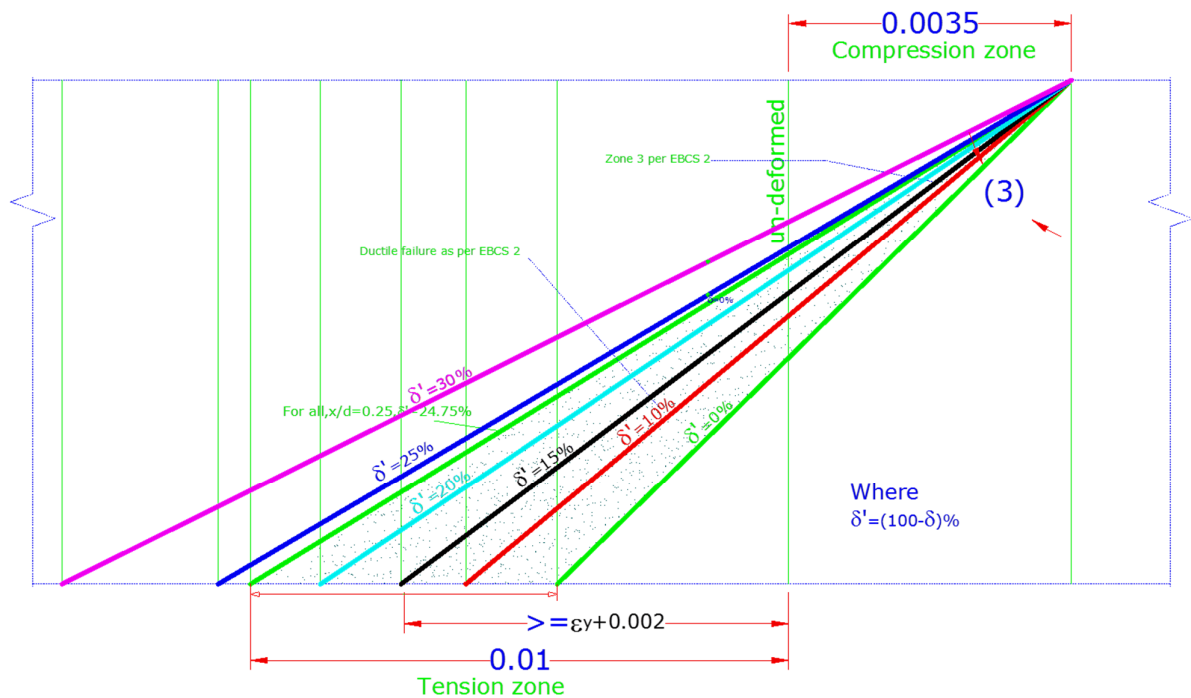


Figure 25 strain diagram in ultimate limit state for different moment redistributions

But in the above diagram the maximum possible moment redistribution could be 24.75% hence 20% moment redistribution will be the safest one for 0.01 maximum strain of bottom steel.

STRAIN AND STRESS DIAGRAM OF CONCRETE AND STEEL

In ultimate limit state the design of section and design aid of EBCS 2 part 2 preformed based on the assumption of stress and strain diagram given in fig 4.2 and fig 4.4 of the code for

⁶⁵ Proof strain is taken as 0.002 for $f_{yk}=f_{cd,2}$, therefore if $\varepsilon_t \geq \varepsilon_y$, $\varepsilon_t = \varepsilon_y + 0.002$ in order to have tension controlled failure.

concrete and steel respectively. It recommends either parabolic rectangular stress block or equivalent rectangular stress block⁶⁶ can be used for design of a section

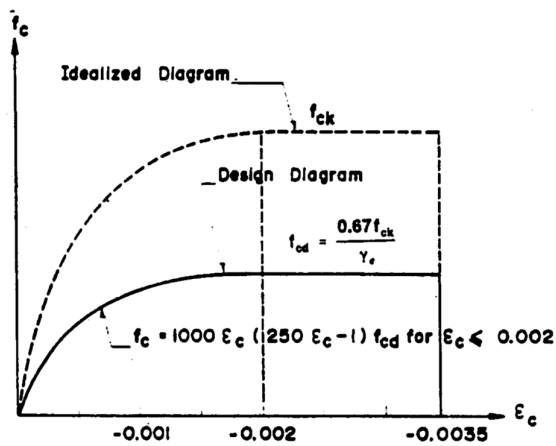


Figure 26 parabolic rectangular stress- strain diagram for concrete in compression (As per EBCS 2 fig 4.2)

Here in the above figure the formula ($f_{cd} = \frac{0.67 f_{ck}}{\gamma_c}$) is not correct, hence shall be written as ($f_{cd} = \frac{0.67 f_{cu}}{\gamma_c}$).

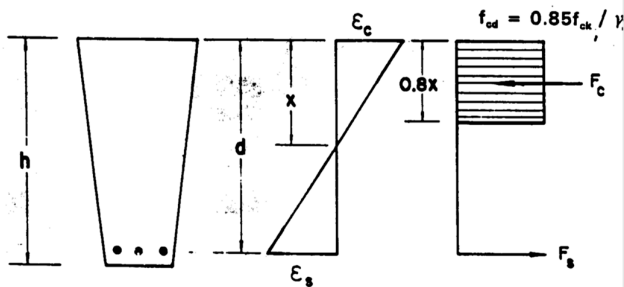


Figure 27 Rectangular stress block

⁶⁶ EC has third alternative which bilinear stress strain block.

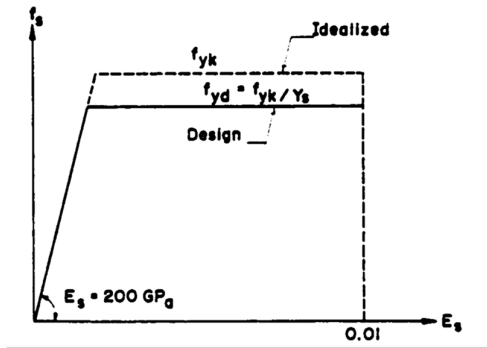


Figure 28 Steel stress diagram

Section design

The design of a section⁶⁷ is presented in part II of the code (EBCS 2) in form of table and chart (table 1a and 1b and chart 1) based on the assumption $f_{cd} = 0.68f_{cu}/\gamma_c$ other than $f_{cd} = 0.67f_{cu}/\gamma_c$ (as expressed in part I of the code) and maximum relative neutral axis depth as 0.448 for 0% redistribution and 0.208 for 30% redistribution and moments are taken about the tension steel. Besides, table and the chart are prepared based on parabolic rectangular stress block and The ration of the relative compression force in concrete (α_c) (in equation 1&2) to relative neutral axis depth and the ration of the relative distance from outer most fiber under compression to the application of the compressive force C_c (β_c) (in equation 3&4 of the code) to relative neutral axis depth is given in the graph below.

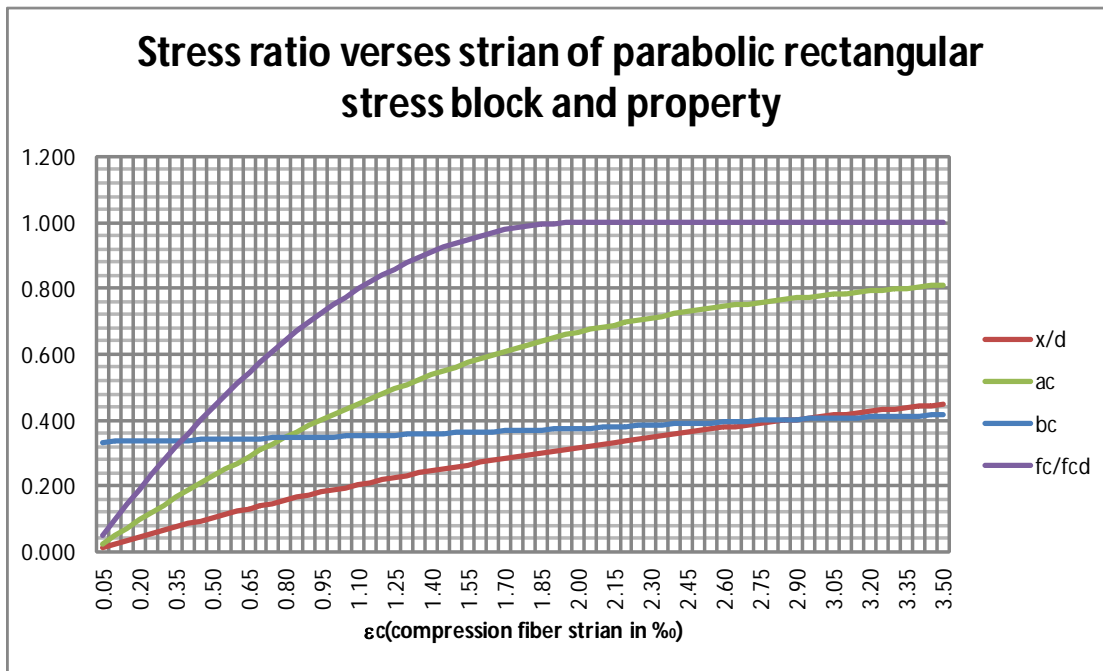


Figure 29 Stress ratio verses strain

Where

⁶⁷ Only BS presents simplified formula for section design

For $\varepsilon_{cm} \leq 0.002$

$$a_r = \frac{\varepsilon_{cm}}{12}(6 - \varepsilon_{cm}), \text{ or } \alpha_c = \frac{\varepsilon_{cm}}{12}(6 - \varepsilon_{cm})k_x \quad (143)$$

$$K_a = \frac{8 - \varepsilon_{cm}}{4(6 - \varepsilon_{cm})}, \text{ or } \beta_c = \frac{8 - \varepsilon_{cm}}{4(6 - \varepsilon_{cm})}k_x \quad (144)$$

For $0.002 \leq \varepsilon_{cm} \leq 0.0035$

$$a_r = \frac{(3\varepsilon_{cm} - 2)}{3\varepsilon_{cm}}, \text{ or } \alpha_c = \frac{(3\varepsilon_{cm} - 2)}{3\varepsilon_{cm}}k_x \quad (145)$$

$$K_a = \frac{\varepsilon_{cm}(3\varepsilon_{cm} - 4) - 2}{2\varepsilon_{cm}(3\varepsilon_{cm} - 2)}, \text{ or } \beta_c = \frac{\varepsilon_{cm}(3\varepsilon_{cm} - 4) - 2}{2\varepsilon_{cm}(3\varepsilon_{cm} - 2)}k_x \quad (146)$$

And

$$C_c = a_r f_{cd} b x, \text{ or } C_c = \alpha_c f_{cd} b d \quad (147)$$

$$a = K_a x, \text{ or } a = \beta_c d \quad (148)$$

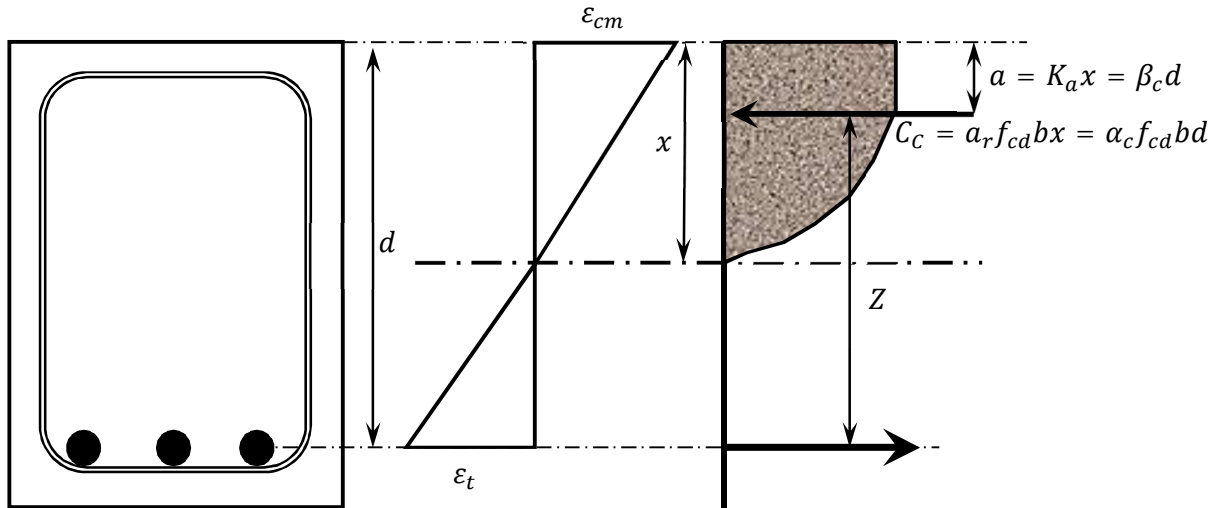


Figure 30 stress and forces in beam section

At ULS

$$\alpha_c = 0.81k_x \text{ and } \beta_c = 0.416k_x$$

$$k_z = 1 - 0.416k_x \quad (149)$$

$$k_s = \frac{1}{f_{yd}(1 - 0.416k_x)} = \frac{(1 - \xi - k_z)(k_m^*/k_m)^2 + k_z}{k_z(1 - \xi)f_{yd}} \quad (150)$$

$$k'_s = \frac{1}{f_{yd}(1 - 0.416k_x)} = \frac{1 - (k_m^*/k_m)^2}{(1 - \xi)\sigma_{s2}} \quad (151)$$

$$\sigma_{s2} = \varepsilon_{s2}E$$

$$k_m = \sqrt{0.81k_x(1 - 0.416k_x)f_{cd}} = \frac{\sqrt{M_{sd,s}/b}}{d} \quad (152)$$

$$k_m^* = \sqrt{0.81k_x^*(1 - 0.416k_x^*)f_{cd}} \quad (153)$$

$$A_{s1} = \frac{k_s M_{sd,s}}{d} \rho \quad (154)$$

$$A_{s2} = \frac{k'_s M_{sd,s}}{d} \rho' \quad (155)$$

The general table 1a and 1b are applicable only to class one works, it should be modified as per partial safety factor of pertinent concrete class. The design chart 1 can be applied to any class of concrete. The general table 1b is done based on $d'/d = 0.07$, however, for other type of d'/d correction using equation 12 and 13 can be used.

$$\rho = \frac{k_s \text{ for } \xi_{actual}}{k_s \text{ for } \xi_{0.07}} \quad (156)$$

And

$$\rho' = \frac{k'_s \text{ for } \xi_{actual}}{k'_s \text{ for } \xi_{0.07}} \quad (157)$$

Table 23 Questioner and response

Respondents type	Question	Number of respondent	Response (%)		
			Y	N	NC
ME	21. Do you have a chance to approve and check slabs analyzed by finite element software?	5/5	40	40	20
ME	22. If yes, EBCS doesn't have or covered this analysis method, then how do you approved?	0			100
ME	24. If yes, how do you check the assumption of the finite element method such as mesh size supports condition etc?	0			
ME	25. How do you check if slabs are irregular?	0			100
ME	26. Have you ever check slab designed based on yield line method or strip method?	4/5	20	60	20
ME	28. Do you think slab designs are safe?	5/5	60	20	20
ME	29. Do you think slab designs are economical?	5/5	20	60	20
ME	30. Do you believe our regulations are strong enough in approving and checking structural design?	5/5	20	60	20

Respondents type	Question	Number of respondent	Response (%)		
			Y	N	NC
CE	29. Do you think Poisson's ratio have effect in one way slab reinforcement,	3/5	40	20	40
CE	40. Have you ever compare the results of some method?	7/10	70		
CE	43. In using table A.1. For computing bending moment of two slabs recommends the beams supporting the slab shall have minimum depth in order to be unyielding, have you ever check the minimum depth requirement of the beam?	7/10	40	30	30
CE	44. The code recommends either to use the moment coefficient in table A.1. Or the equation given A.2 to A.4 do you think these give the same result?	5/10	30	10	10
CE	45. The code states the reinforcement calculated either for equation A.2 to A.4 and table A.1. Shall be distributed only in the middle strip only and to provide minimum reinforcement at the edges, have you ever apply this?	5/10	10	40	50

CE	46. The code states in using the equations and table A.1, moment redistribution is not recommended do you really understand what it means?	5/10	20	20	60
CE	47. In EBCS it provides two methods to resolve the difference in moment at supports, have you ever apply either or both of them in design?	7/10	20	40	40
CE	48. In EBCS it provides two methods to resolve the difference in moment at supports and set criteria , where as British code recommends elastic method and no criteria is set, do you think this is advantageous over British standard?	7/10	10	40	40
CE	49. Do you think the method set in EBCS is time saving and economical method?	6/10	15	35	50
CE	52. In cantilever design, some say cantilever beam shall be provided to support cantilever slab even it is design 1m width and some say it doesn't need cantilever beam because already the cantilever is designed as 1m width for all loading case and deflection, which one do you think correct?	6/10	30	10	60
CE	54. The design table and chart in EBCS 2 are based on parabolic-rectangular stress block? Have you ever used in design rectangular stress block?	8/10	60	20	20
CE	56. Do you really understand moment redistribution and its application?	8/10	60	10	30
CE	57. Have you ever apply moment redistribution in design of one way slab and two way slabs?	8/10	50	30	20
CE	60. In detailing of slabs, do you think EBCS 2 and EBCS 2 part 2 provide sufficient information?	8/10	20	60	20
CE	62. Have you ever calculate anchorage bond length, lap length, hops based on EBCS for design?	7/10	60	10	30
CE	64. In EBCS it states how to compute moment for partial fixity which is not stated in any of the above expressed codes? Have you ever use it in practice?	7/10	10	60	30
CE	67. Do you think the payment for designing of slabs and other structures is affordable?	8/10	30	30	40
CE	68. As per researches the cost of slabs accounts about 59 % of the building structural cost, do you think your designs are economical?	8/10	40	40	20
CET	8. Do you believe slabs are as designed well?	3/3		100	
CET	9. Does drawings are descriptive?	3/3		100	

RT Question #R Response (%)

			20% of main reinforcement	30% of main reinforcement	10% of main reinforcement	Exactly	Only minimum reinforcement	Other
CE	30. How much reinforcement do you use in secondary direction?	7/10	40				30	30
			Elastic method (moment distribution method)	Simplified method	Yield line method	Other method:		
CE	32. Which method do you use in one way slab analysis?	8/10	22.5	22.5	12.5	22.5		20
			Elastic method (moment distribution method)	Simplified method	Yield line method	Strip method	Other method:	
CE	33. Which method of analysis one way slab do you learn in university?	7/10	27.5	7.5	22.5	12.5		30
			ACI,	BS,	EC,	IS	Others: specify	
CE	34. Where do you get the simplified method?	4/10	15	5	10	10		60

R Question #R Response (%)
T

			Elastic method (moment distribution method)	Simplified method	Yield line method	Strip method	Finite element method(SAP and/or ETABS moment counter)	Finite element method(SA FE)	Finite element method (other)	Other method:
CE	38. Which method do you use in two way slab analysis?	6/10	3.33	20		5	28.33	3.33		40.10
CE	39. Which one of methods gives you minimum reinforcement?	6/10	10	20	20	10				
CE	41. Which one of methods does you think more safe?	8/10	10	20	10	10	25	5		20
	<i>Other method:</i>									

RT	Question	#R	Response (%)
CE	42. In EBCS 2 section A.3.1.(2) states slab analysis method based of coefficients from table A.1 assumes the slab is loaded to single total load uniformly distributed and the partition wall load also can be converted to equivalent uniform load over the area satisfying the condition that the partition load is less than 20% of the total load, How do you treat for partition walls heavier than 20%	1/10	10% say ignore it 90% never comment

RT	Question	#R	Response (%)					
			<i>The same</i>	<i>Different</i>	<i>Other</i>	<i>Never comment</i>		
CE	51. Commonly we have two types of cantilever based on loading, one is balcony and the other is verandah? Do you take the same loading or different? 1. With cantilever beam?	7/10	30	30	10	30		
			<i>As per the tables and charts given in EBCS 2 part 2</i>	<i>Using design equation</i>	<i>Using finite element method</i>	<i>Other method:</i>	<i>Never comment</i>	
CE	53. Which method design do you use in one way slab design?	8/10	30	30	20		20	
			<i>Easy to use and understand</i>	<i>Medium</i>	<i>Complex to understand and use</i>	<i>No comment</i>		
CE	55. Do you think the charts and tables in EBCS 2 parts 2 are easy to use and to understand?	7/10	30	40		30		
			$\leq 10\%$	15%	20%	25%	30%	<i>No comment</i>
CE	58. How much percent do you use on redistribution?	7/10	20	30	10	10		30
			<i>ACI,</i>	<i>BS,</i>	<i>EC,</i>	<i>IS</i>	<i>No comment</i>	
CE	61. If in Q#60 you say No, from where do you gate the method of detailing?	7/10	20	20	20	10	30	
			<i>As one way solid slab</i>	<i>As ribbed slab</i>	<i>Other</i>	<i>No comment</i>		
CE	63. In designing of ribbed slab EBCS recommended to design as one way solid slab, if the criteria set on EBCS 2 section 3.7.5. (5), how do you analyze ribbed slabs?	6/10	30	20	10	40		

RT	Question	#R	Response (%)								
			By changing to Regular	Yield line method	Strip method	Using SAFE	Empirical formal	Classical method	Numerical method	Moment couture for SAP or ETABS	Other :
CE	65. Which method analysis do you use for irregular slabs analysis?	8/10	19.9	3.33	12.2	26.6				18.3	
CE	66. Which method analysis do you use for analysis slab with holes?	8/10	10	10		33.3	3.33			23.3	23

The other method of analysis and design used by designers are yield line and strip method (by 60% respondents) and about 60% say the design of the slab by any of the methods are safe but not economical and our regulation is not strong enough in structural design checking. On the contrast, 70% of respondents verify or check designs by other methods and check whether the slab supporting unyielding beam satisfies the criteria or requirement set by the code in ANNEX A (40%).

SERVICEABILITY REQUIREMENTS

EBCS 2 covers only crack and deflection limit states, other limit states such as vibration are not covered. As discussed in the design fundamentals the deflection of a slab shall not adversely affect the proper function and appearance of the structure, this can be ensured by either limiting the deflection or taking the minimum effective depth (span to depth ratio). Similarly to improve the durability and appearance the crack width shall be limited⁶⁸.

The final deflection (δ) of a horizontal member shall not greater the $l_e/200$ ⁶⁹. For floors supporting or attached non-structural components such as partitions and finishes sensitive to deflection, the deflection (δ) after attachment of the non-structural components shall not greater the $l_e/350$ ⁷⁰, the maximum limit of deflection is 20 mm. it is clear the design load and design strength in ultimate limit state and serviceable limit state is assumed to be the same.

EFFECTIVE DEPTH LIMIT

Unless computation of deflection indicates smaller value the minimum effective depth or the maximum span to depth ratio can be computed by equation 5.3 and β_a is given in table 5.1 of the code⁷¹, for slabs carrying partition likely to crack $\beta_a \leq 150/l_o$ where l_o the distance between zero moment and for cantilever twice the length of the cantilever slab.

$$\frac{l}{d} = \beta_a \left(0.4 + \frac{0.6f_{yk}}{400}\right)^{-1} \quad (158)$$

⁶⁸ This thesis is limited to depth of slab less than 200mm hence excess crack can be controlled by limiting the space or use the pertinent size of bar as per the code.

⁶⁹ In IS it is taken as 250.

⁷⁰ In EC and BS it is taken as 500

⁷¹ It is based on shortest span for two slab supported in beams

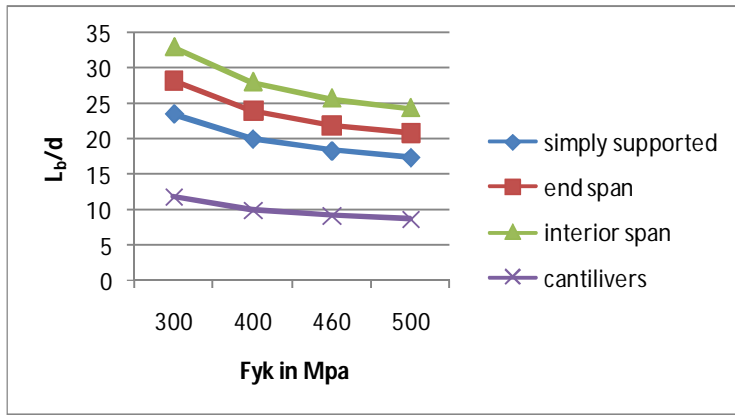


Figure 31 Span to effective depth ration for one way slab

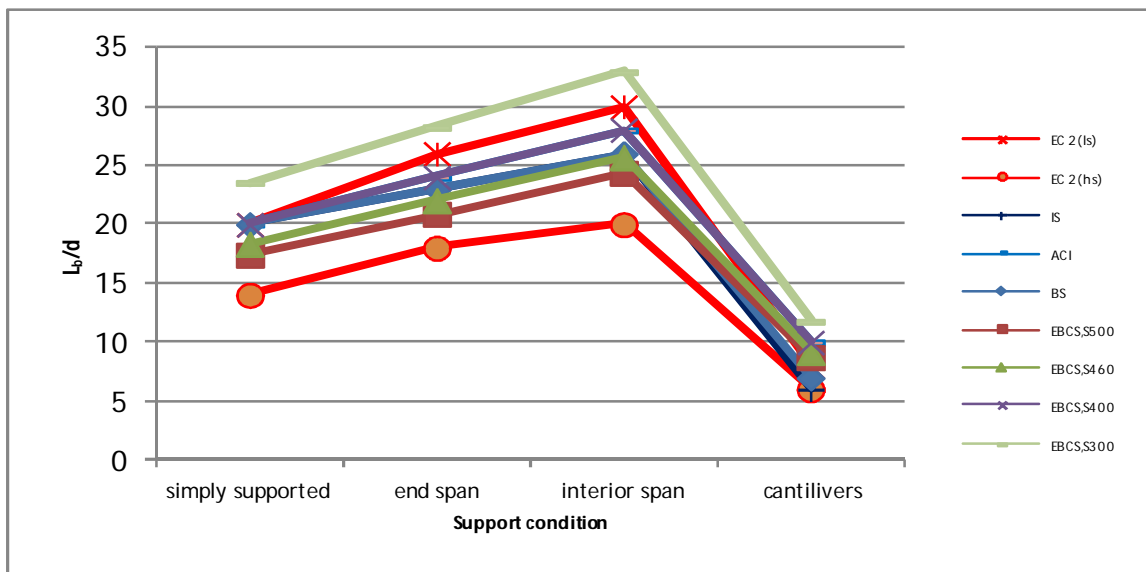


Figure 32 Span to effective depth ration for one way slab of different codes

This graph shows the effective depth is lesser in EBCS as compare to other codes.

Table Span to effective depth⁷² ration for two way slab of l_y/l_x of 2:1 and 1:1 and grade

⁷² EBCS doesn't specify to what span limit do the span to effective depth works and the limit deflection shall be checked, where as in BS and IS it is applicable for spans up to 10 m and should be multiplied by 10/span except for cantilevers where the design should be justified by calculation. And in EC it is applicable for spans up to 7 m and should be multiplied by 7/effective span. Moreover, the IS standard states, it can be taken the given span to effective depth ration without checking of deflection of the slab for span 3.5m and live load less than 3kN/m².

Table 24 Span to effective depth⁷³ ration for two way slab of l_y/l_x of 2:1 and 1:1 and grade

Support condition	Steel grade							
	S300		S400		S460		S500	
	(2:1) ⁷⁴	(1:1)	(2:1)	(1:1)	(2:1)	(1:1)	(2:1)	(1:1)
simply supported	29	41	20	35	18	32	17	30
end span	35	47	24	40	22	37	21	35
interior span	41	53	28	45	26	41	24	39
cantilevers	14	12	10	10	9	9	9	9

CALCULATION OF DEFLECTION

Calculation of deflection is difficult for it depends on many parameters; the code gives method of computing deflection for immediate and long term deflections as given in equation 5.4 to 5.8 of the code⁷⁵. This is based on un-cracked transformed section.

The immediate deflection δ is given by

$$\delta_{short} \leq \begin{cases} \delta_i + \delta_{ii} \\ \delta_{max} \end{cases} \quad (159)$$

$$\delta_i = \beta \frac{M_{cr}}{E_{cm} I_i} l_x^2, \text{ uncracked transformed section} \quad (160)$$

$$\delta_{ii} = \beta \frac{M_k - M_{cr}}{0.75 E_s A_s z (d - x)} l_x^2, \text{ 75\% of cracked section} \quad (161)$$

$$\delta_{max} = \beta \frac{M_k}{E_s A_s z (d - x)} l_x^2, \text{ fully cracked section} \quad (162)$$

Where

$$M_{cr} = 1.7 f_{ctk} Z = 1.7 f_{ctk} \frac{b D^2}{6}, \quad Z = \frac{I}{y} = \frac{b D^2}{6} \quad (163)$$

Where β is presented here below for one way and two way slab separately, it is based on Timoshenko's calculation.

Table 25 formula for deflection at critical sections for one way slabs

No.	Slab condition	β	M_k
-----	----------------	---------	-------

⁷³ EBCS doesn't specify to what span limit do the span to effective depth works and the limit deflection shall be checked, where as in BS and IS it is applicable for spans up to 10 m and should be multiplied by 10/span except for cantilevers where the design should be justified by calculation. And in EC it is applicable for spans up to 7 m and should be multiplied by 7/effective span. Moreover, the IS standard states, it can be taken the given span to effective depth ration without checking of deflection of the slab for span 3.5m and live load less than 3kN/m².

⁷⁴ l_y/l_x

⁷⁵ It doesn't specify, if the equation is for applicable to one way slab or two way slab or for both. Moreover, it doesn't specify whether it is based on short or long span.

3	Cantilever slabs with distributed load	0.250	$wl^2/2$
3	Cantilever slabs with point load at the end of cantilever	0.333	W-L
1	Simply supported slabs spanning in one direction	0.104	$wl^2/8$
2	Continuous slab spanning in one direction $n=(MA-MB)/M$	$=0.104*(1-n/10)$	$wl^2/8-0.5*(MA+MB)$

Table 26 coefficients for deflection calculation, where $\beta = \alpha/12\alpha_x$

Panel number	Panel type	Coefficient	ly/lx									
			1.0	1.1	1.2	1.3	1.4	1.5	1.75	2		
1		α	0.015	0.018	0.021	0.023	0.025	0.026	0.029	0.03		
		α_x	0.024	0.028	0.032	0.036	0.039	0.041	0.045	0.049		
		β	0.052	0.054	0.055	0.053	0.053	0.053	0.054	0.051		
2		α	0.019	0.021	0.024	0.025	0.027	0.028	0.03	0.031		
		α_x	0.028	0.032	0.036	0.039	0.041	0.044	0.048	0.052		
		β	0.057	0.055	0.056	0.053	0.055	0.053	0.052	0.050		
3		α	0.019	0.024	0.028	0.033	0.037	0.041	0.048	0.054		
		α_x	0.028	0.033	0.039	0.044	0.047	0.051	0.059	0.065		
		β	0.057	0.061	0.060	0.063	0.066	0.067	0.068	0.069		
4		α	0.025	0.03	0.035	0.039	0.043	0.046	0.052	0.056		
		α_x	0.035	0.04	0.045	0.049	0.053	0.056	0.063	0.069		
		β	0.060	0.063	0.065	0.066	0.068	0.068	0.069	0.068		
5		α	0.023	0.025	0.027	0.028	0.029	0.03	0.031	0.031		
		α_x	0.035	0.037	0.04	0.043	0.044	0.045	0.049	0.052		
		β	0.055	0.056	0.056	0.054	0.055	0.056	0.053	0.050		
6		α	0.023	0.03	0.038	0.047	0.055	0.064	0.084	0.101		
		α_x	0.035	0.043	0.051	0.057	0.063	0.068	0.08	0.088		
		β	0.055	0.058	0.062	0.069	0.073	0.078	0.088	0.096		
7		α	0.033	0.038	0.042	0.046	0.049	0.051	0.056	0.059		
		α_x	0.043	0.048	0.053	0.057	0.06	0.064	0.069	0.073		
		β	0.064	0.066	0.066	0.067	0.068	0.066	0.068	0.067		
8		α	0.033	0.042	0.051	0.06	0.069	0.077	0.095	0.111		
		α_x	0.043	0.051	0.059	0.065	0.071	0.076	0.086	0.096		
		β	0.064	0.069	0.072	0.077	0.081	0.084	0.092	0.096		
9		α	0.049	0.058	0.068	0.073	0.085	0.095	0.109	0.122		
		α_x	0.056	0.064	0.072	0.079	0.085	0.089	0.1	0.107		
		β	0.073	0.076	0.079	0.077	0.083	0.089	0.091	0.095		

And the long term deflection is given by

$$\delta_{long} = \Delta\delta_{short} \quad (164)$$

Where

$$\Delta^{76} \geq \begin{cases} \left[2 - \frac{1.2A'_s}{A_s}\right] \\ 0.6 \end{cases} \quad (165)$$

Mainly floors are singly reinforced structure. Hence, $A'_s = 0$, implies $\Delta = 2$ which is relatively large as compare to other cods like IS which is $\Delta = 1.6$ for floor system.

Taking panel type 4, $l_y/l_x=1$ and 3kN/m^2 live load, 1.5kN/m^2 for partition load, 2.15kN/m^2 for plastering, cement screed and floor finish, based on the above equations and tables and considering $A'_s = A_{smin}$ and cover of 15cm and diam. 8 bar. Material C-25 and S-300 are taken as material grade. The test of EBCS equation 5.3 and equation 5.4,5.5,5.6,5.7,5.8 is summarized in the table below:

Table 27 Deflection, Span to effective depth ration and depth of slab of different codes

lx	Over all depth				effective depth				l/d		Deflection							
	as per deflection requirement	As per EBCS equation 5.3	As per IS l/D=26	As per BS l/D=26*1.4	as per deflection requirement	As per EBCS equation 5.3	As per IS l/D=26	As per BS l/D=26*1.4	as per deflection requirement	As per EBCS equation 5.3	As per IS l/D=26	As per BS l/D=26*1.4	Deflection limit	as per deflection requirement	As per EBCS equation 5.3	As per IS	As per EC	FE on unyielding beam(SAP2000)
12	810	280	316	330	790	257	293	307	15	46	40	39	20	19.91	57.77	74.4	49.89	37.02
11	700	260	290	302	660	237	267	279	16	46	41	39	20	19.53	52.24	67.68	54.14	31.78
10	580	240	264	275	560	217	241	252	17	46	41	39	20	18.27	41.19	60.65	40.45	26.80
8	370	190	211	220	350	167	188	197	22	47	42	40	20	19.87	38.2	47.59	30.56	20.61
7	290	170	185	192	270	147	162	169	25	47	43	41	20	17.95	32.85	40.55	26.22	16.17
6	205	150	158	165	185	127	135	142	32	47	44	42	20	17.57	27.51	33.51	21.98	12.05
4	80	110	106	100	77	87	83	87	51	45	48	45	20	19.43	16.94	19.46	13.86	5.24
3.5	90	100	93	96	65	77	70	73	53	45	50	47	17.5	13.42	14.13	15.93	11.9	3.85
3	70	90	79	82	50	67	56	59	60	44	53	50	15	13.36	11.7	12.39	6.32	2.68

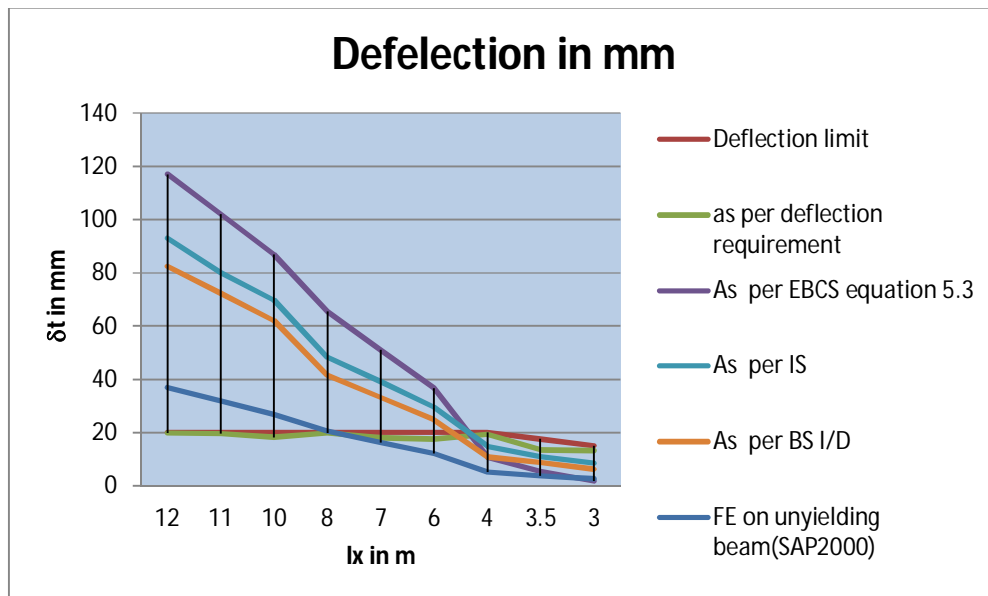


Figure 33 Deflections of slab

⁷⁶ In IS Δ is given as 1.6 which is applicable for creep only, unlike the IS, but EBCS uses for both creep and shrinkage.

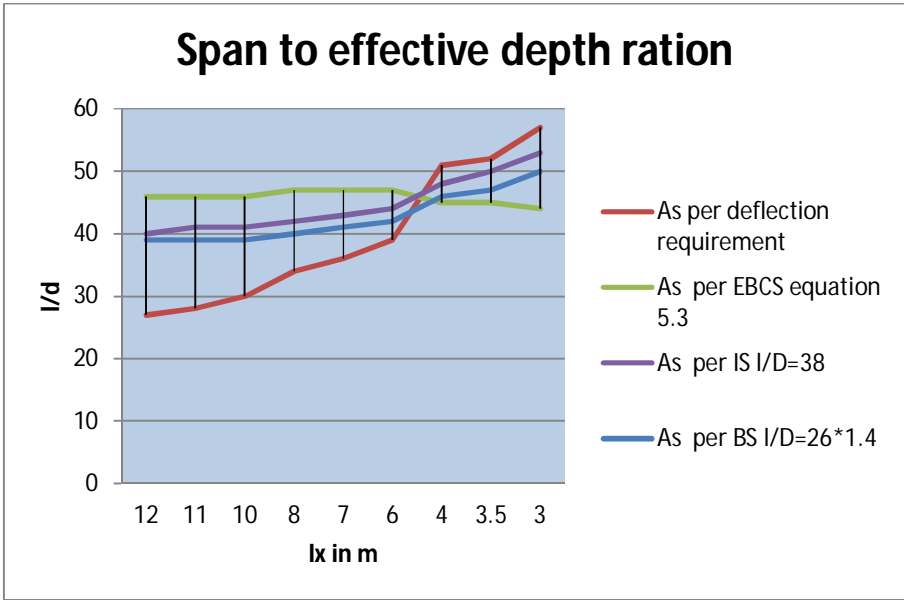


Figure 34 Span to depth ration

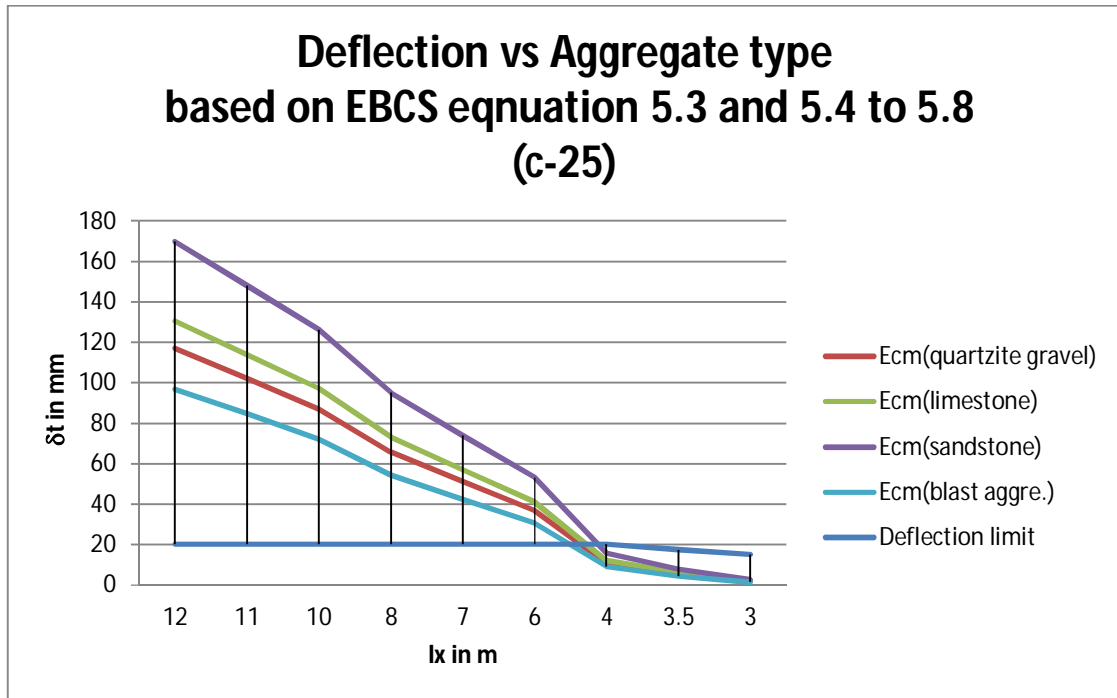


Figure 35 Effect of aggregate on deflection of slab

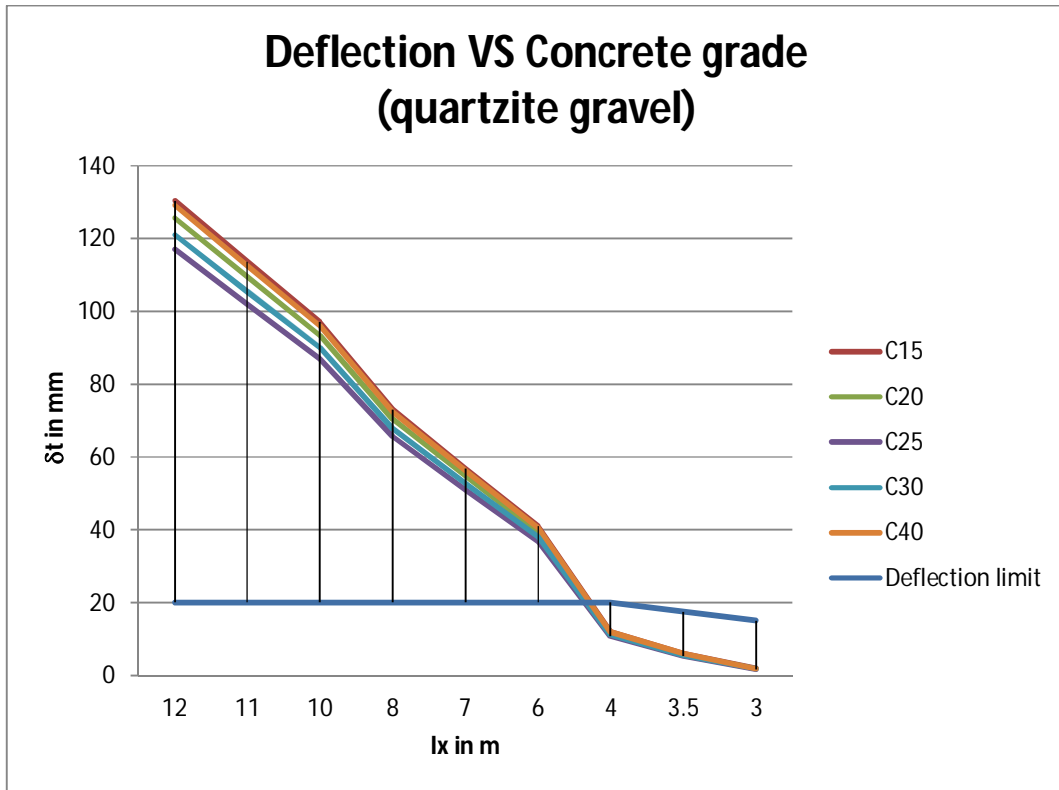


Figure 36 effect of Concrete grade on deflection

From the above charts it is clear the deflection calculation using equation 5.3 can be used up to 4m without checking deflection, aggregate type and concrete grade, however for slabs which span more than 4 meter, the effect of deflection, material and concrete grade shall carefully investigated, and even become significant for large spans. Besides, though EBCS gives larger depth up to 4m, provides extremely lesser depth for larger spans more than 6m. Here is example of failure of slab span of 7.5m,





Figure 37 actual failure of slab by deflection

LIMIT FOR CRACKING

In addition to the minimum reinforcement given in section 7, the minimum reinforcement required to ensure control of crack in slabs is given by:

$$A_{smin} = \frac{0.72A_{ct}}{f_{yk}} \quad (166)$$

Where:- A_{ct} is the area of tension zone of concrete prior to crack.

As discussed above the section at serviceability limit state, the stress distribution is assumed to triangular, hence the section is un-cracked, the maximum tensile stress on concrete tension zone shall be less than or equal to $1.7f_{tck}$. The maximum crack width (w_k) for concrete members for different exposure conditions is given as 0.4, 0.2 and 0.1 for mild, moderate, and sever condition respectively.

Table 28 questioner and response

Respondents type	Question	Number of respondent	Response (%)		
			Y	N	NC
CE	35. Depth of span to depth shows the span to depth ration is larger in EBCS 2 than the other	3/10	10	20	70

	codes? Do you think we are on the safe side?				
CE	36. Other codes give a general span to depth ratio for all two way slabs, where as EBCS 2 gives for 2:1 and 1:1 for intermediate interpolation is allowed. Do you think this is advantageous over the other codes?	4/10	30	10	60
CE	37. In calculating the effective depth for slabs carrying partition likely to crack it is recommended as $\beta_a=150/l_o$, have you ever use this in calculating effective depth?	4/10	10	10	80
CE	59. Have you ever check the deflection of the slab?	8/10	70	20	10
	Why? _____				

Respon dents type	Question	Numb er of respo ndent	Response (%)			
			Y	N	other	NC
	69. Do you believe the designs of slab are given in detail in university or do you believe the time given for such course is sufficient?	8/10	30	30	10	30

Respon dents type	Question	# of resp onde nt	Response (%)			
			Freque ntly	Rarely	Never	other
	70. Have you ever read books and pertinent references to enhance your knowledge and crier?	8/10	50	30		20

On the contrast of the above reality of deflection, 70% of respondents check the deflection and take the depth provided by EBCS is sufficient. On the revers 20% responds extremely disagree with our code. The reason for could be luck of reading habit (50%), weakness in transferring knowledge in university (70%) , luck of something to verify the information given in the code.

DETAILING PROVISION

CONCRETE CLEAR COVER

Minimum cover concrete is required to ensure the safe transmission of bond force, avoid spalling of concrete, and protects steel against corrosion and to have adequate fire resistance, the code provides cover of concrete based on exposure condition and is give as 15, 25, 50mm for mild, moderate and sever exposure respectively.

THICKNESS OF SLAB

The minimum thickness of slab exposed to concentrated and distributed loads is 60 and 80mm respectively.

FLEXURAL REINFORCEMENT

For one way slab the secondary reinforcement⁷⁷ is at least 20% of main reinforcement. The geometrical minimum reinforcement is given by $A_{smin} = 0.5bd/f_{yk}$ where f_{yk} in Mpa. the maximum spacing of bars is given by

$$s_{main} \leq \begin{cases} 2h \\ 350mm \end{cases} \text{ and } s_{sec} = 400mm \quad (167)$$

BOND LENGTH

The bond strength of slabs which is classified non-good (poor) bond condition & can be computed as $f_{bd} = 1.4f_{ctk}$ as per section 7.1.5.1 and all reinforcements shall be anchored to consider the shear cracks arch effect. Moreover, to prevent bond failure bars shall be developed to appropriate embedment length or end anchorage or both.

The development length for slabs based the characteristic compression concrete and tensile characteristic strength of steel is given bay:

$$\frac{l_b}{\phi} = 0.7394f_{yk}/f_{ck}^{\frac{2}{3}}, \quad (168)$$

This equation is derived from equation 2.1, 2.2, 7.2 and 7.3 for deformed bar and other than good bond condition and given in the figure and table below.

⁷⁷ Taking Poison's ratio of 0.2

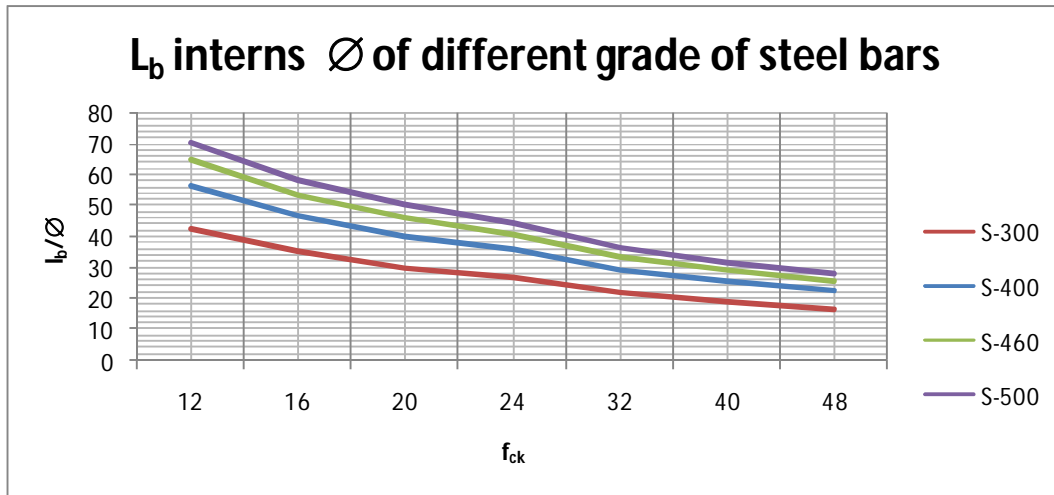


Figure 38 l_b interns \varnothing of different grade of steel bars

Table 29 l_b interns \varnothing of different grade of steel bars

		Steel grade (f_{yk})			
		S-300	S-400	S-460	S-500
f_{ck}	12	42	56	65	71
	16	35	47	54	58
	20	30	40	46	50
	24	27	36	41	44
	32	22	29	34	37
	40	19	25	29	32
	48	17	22	26	28

Similarly the anchorage length particularly for slab assuming straight bar anchorage is given:

$$l_{b,net} = 0.7394\varnothing \left(\frac{f_{yk}}{f_{ck}^{\frac{2}{3}}} \right) \left(\frac{A_{scal}}{A_{seff.}} \right) \geq \begin{cases} 0.7394\varnothing f_{yk} / f_{ck}^{\frac{2}{3}} \\ 10\varnothing \\ 200mm \end{cases},^{78} \quad (169)$$

The lap length depends on the basic anchorage length and the distance between center of laps and the spacing between bars and can be summarized graphically as follows. For similar assumption as above:

$$l_0 \geq \begin{cases} a_1 l_{b,net} \\ l_b \\ 10\varnothing \\ 200mm \\ 0.3a_1 l_b \end{cases} \quad (170)$$

⁷⁸ For other anchorage types shall multiplied by 2

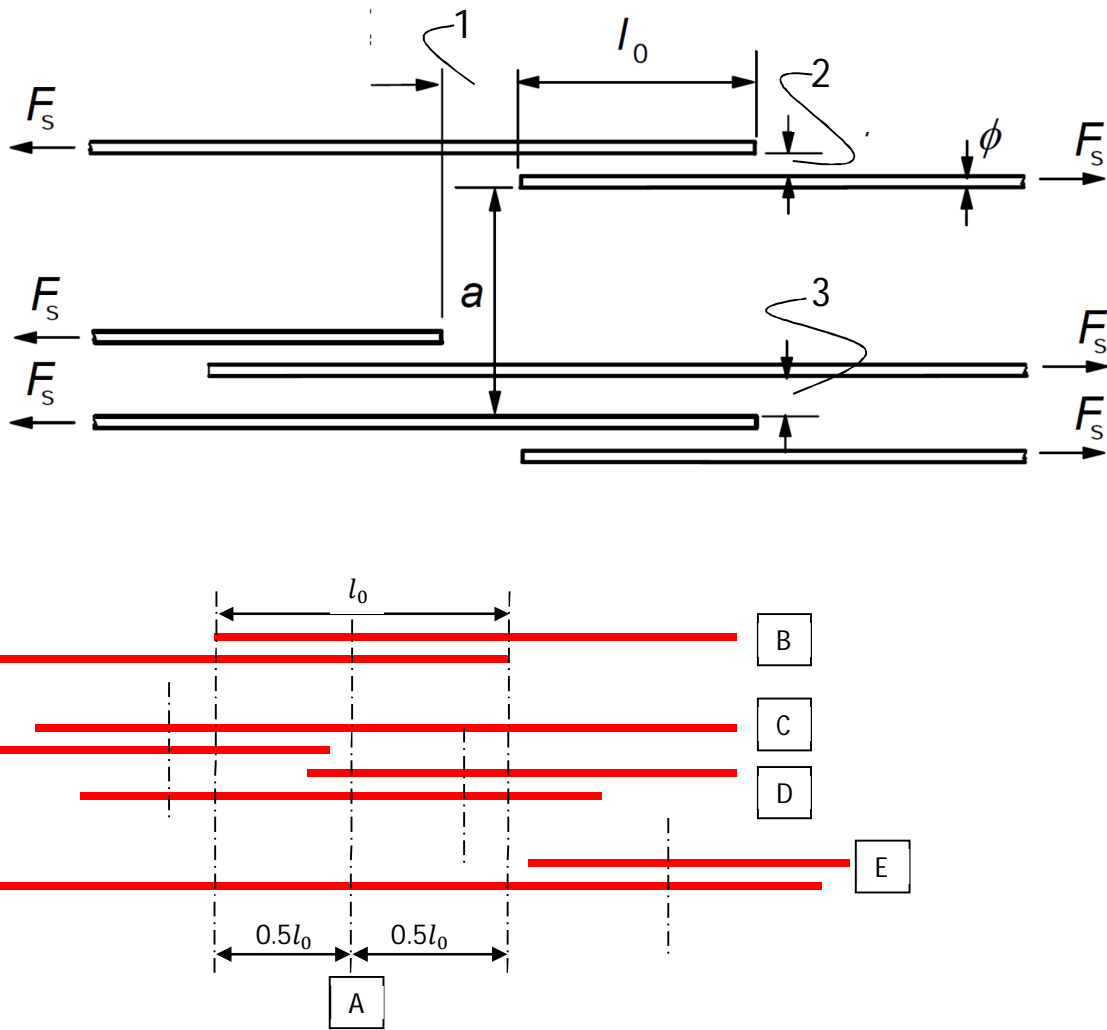


Figure 39 Adjacent laps (Note: -"1" indicates clear spacing between adjacent laps is $0.5l_0$, "2" indicates the clear distance between bars lapped together is $2\phi \geq 20mm$ where as "3" is not stated in EBCS code⁷⁹).

To find a_1 from table 7.3 of the code needs the percentage of lapped reinforcement within the lap length, from the this figure taking section at A, The centers of lap bars B and D are inside l_0 whereas bars C and D outside of l_0 which can be excluded in counting, there for the percentage of reinforcement lapped with in lap length is 50%.

CURTAILMENT RULE OF BARES

The Curtailment based on the tensile force diagram of member and can be detailed using the figure 7.2 of the code, where a_l is equal to the effective depth(d).

⁷⁹ Rather in EC.

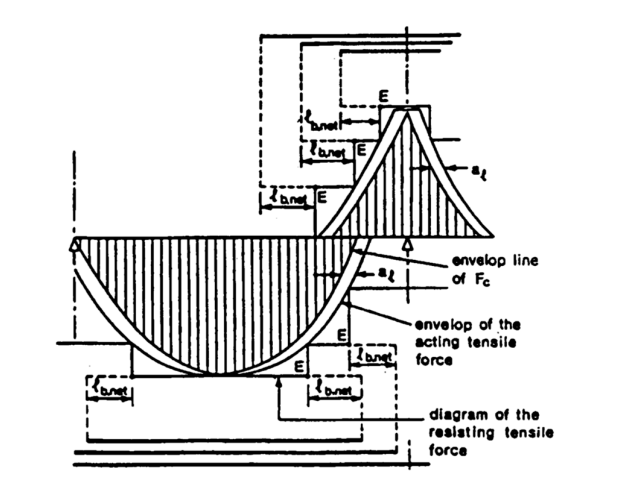


Figure 40 Tensile force diagram for curtailment of bars

The anchorage of bottom reinforcement is presented as below based on the code recommendation:

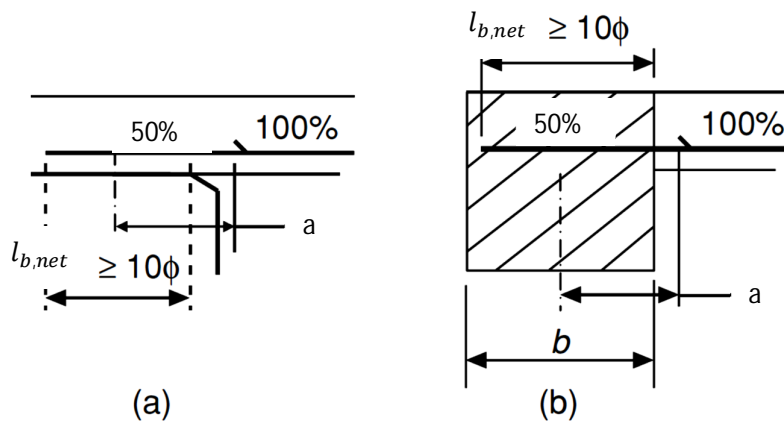


Figure 41 anchorage of bottom reinforcement a) for direct support and b) indirect support "a" is not stated in this code.

In general, EBCS lacks detailing as compared to other codes.

DESIGN DOCUMENT ASSESSMENT AND EVALUATION (COLLECTED FROM MUNICIPALITY) (STAGE 3)

Collecting of analysis and design document form Municipalities is tough for many reasons; one of reason is luck willing of owner to give document and the other reason is fear of municipal engineers in loss of document and believes their weakness could be exposed. Apart from this, 23 documents were collected. Moreover, it is so difficult even to evaluate for these use different method of presentation and analysis and design report submitted to municipality. However, to simplify the research representative 14 documents and few variables which are common and important are taken and evaluated and presented as follows:

FUNCTION OF BUILDING COVERED IN THE DESIGN REPORT

Unlike the EBCS 1, the municipality classification is in general term, which could include different functions in one category. Functions included in the document are presented below.

Table 30 Building functions

S.No.	Function	Frequency	Percent
1	COMMERCIAL	1	7.1
2	GUEST HOUSE	1	7.1
3	HOTEL	2	14.3
4	MIXED USE	3	21.4
5	NC(Note Clear)	2	14.3
6	RESIDENTIAL	4	28.6
7	SHOP AND APARTMENT	1	7.1
	Total	14	100.0

Fortunately, almost all number of story (2 to 15) is covered in the design report documents. Moreover, as expressed in chart ____, though mostly the reports covered regular slabs (in 10 documents), but slabs which are irregular (in 10 documents) (which can be regularized for design purpose) and highly irregular (in 10 documents) (which are very complex and difficult to analyze) are included. Looking in pie chart ____most document cover slabs are two way slabs which accounts 52% and 9% one way slab including ribbed slab and cantilever accounts about 36%

NUMBER OF STORIES INCLUDING BASEMENTS COVERED IN THE DESIGN REPORT

Table 31 Function * Story cross tabulation

Function	Story					
	10	15	2	4	8	9
Commercial						1
Guest house				1		
Hotel				2		
Mixed use		1		1	1	
Not clear (NC)			1			1
Residential			3	1		
Shop and apartment	1					

Function	Story					
	10	15	2	4	8	9
Commercial						1
Guest house				1		
Hotel				2		
Mixed use		1		1	1	
Not clear (NC)			1			1
Residential			3	1		
Shop and apartment	1					
Total	1	1	4	5	1	2

Table 32 Function*Story*live load*Partition*Depth of slab cross tabulation

Depth	partition	live	Function	Story					
				10	15	2	4	8	9
150	0	3	COMMERCIAL						1
	0	3	HOTEL				1		
	1	2	RESIDENTIAL			1			
	2.53	2	RESIDENTIAL			1			
160	1	7	MIXED USE		1				
	1.3	3	NC						1
170	1	4	GUEST HOUSE				1		
180	NS	NS	NC			1			
NS	0	3	HOTEL				1		
	0	5	MIXED USE					1	
	1	2	SHOP AND APARTMENT	1					
	NS	NS	RESIDENTIAL				1		
VAR	0.23	2	RESIDENTIAL			1			
	1	3	MIXED USE				1		

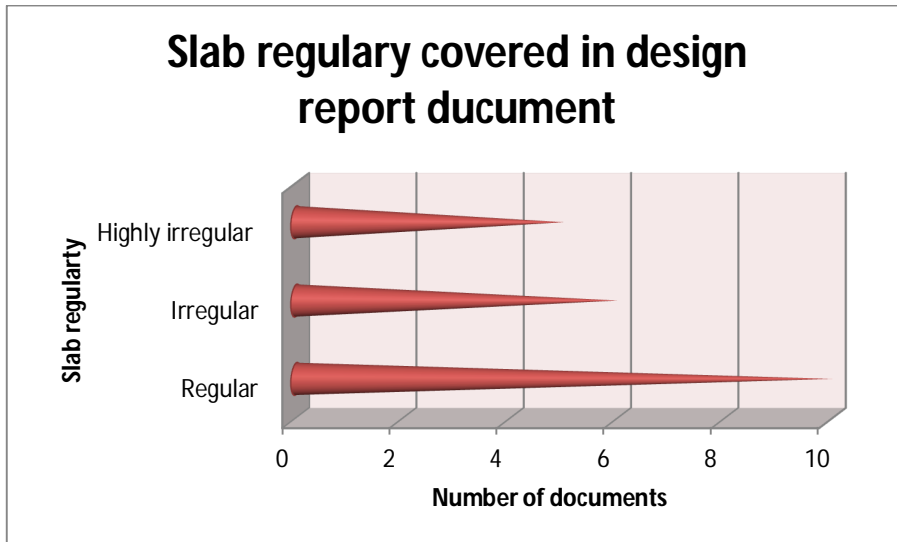


Figure 42 Slab irregularity in practice

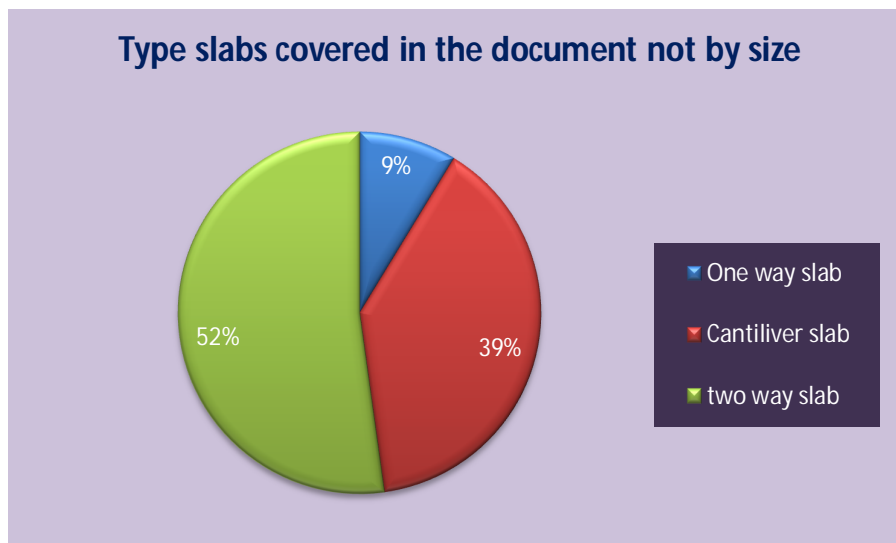


Figure 43 types of slabs in practice

METHOD OF ANALYSIS AND DESIGN COVERED IN THE DOCUMENT

Surprisingly, 30% of documents never include the analysis and design part. Even the documents which cover the analysis and design part, there is no consistency in analysis and design methods of slab. For instance, in pie chart left top of fig 46, some of the documents take concrete density of 25kN/m^3 (64.29%), 24 kN/m^3 (28.57%) and in some documents it is not even expressed (7.14%). Moreover, 78.57% of the designer's consider concrete strength of $f_{cu}=25\text{N/mm}^2$ and 7.14% took $f_{cu} = 30\text{ N/mm}^2$ and the rest didn't show what they took. Similarly almost all (92.86%) uses S-300 steel and few take S-350.

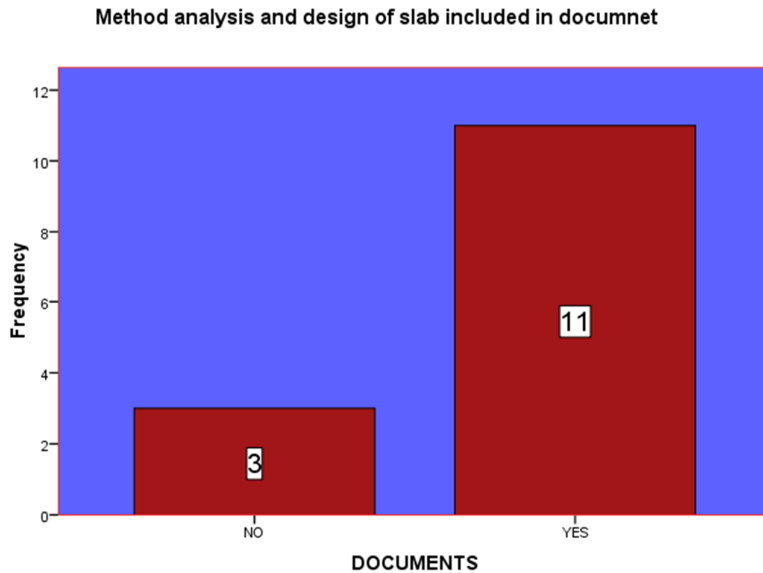


Figure 44 method of analysis and design in practice

In other way, which is very difficult to believe is density of HCB wall, undoubtedly and clearly stated in EBCS 1(14kN/m³) is taken differently. Only 21.43% designers take similar to EBCS 1's density, in contrast, in 50% of the document the density of HCB is not clear and 14.8% took 0 to 1.2.

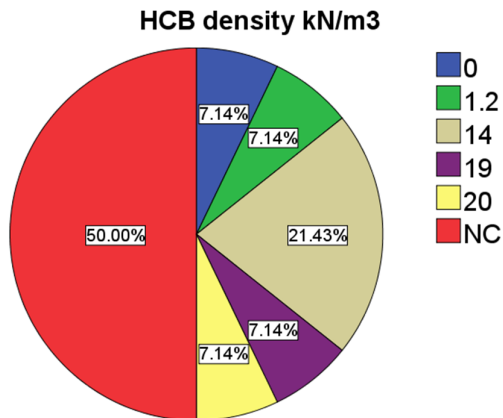


Figure 45 Hollow block concrete (HBC) density

Most designers claim slab thickness of 150mm becomes mandatory for construction simplicity and form work economy, similarly in pie chart bottom left of fig 46 shows similar trend which is about 28.57% use 150mm thickness over all slab system, and similar percentage does not express the depth they took, in contrast 14.29% variable slab depth with in single building, the rest take higher depth.

The other surprising issue is about the designers, two of the design documents are done by mechanical engineer (ME) and four of them are done by practicing engineers and above.

Graduate engineers participate in designing 3 buildings but the rest are not clear by whom it is prepared.

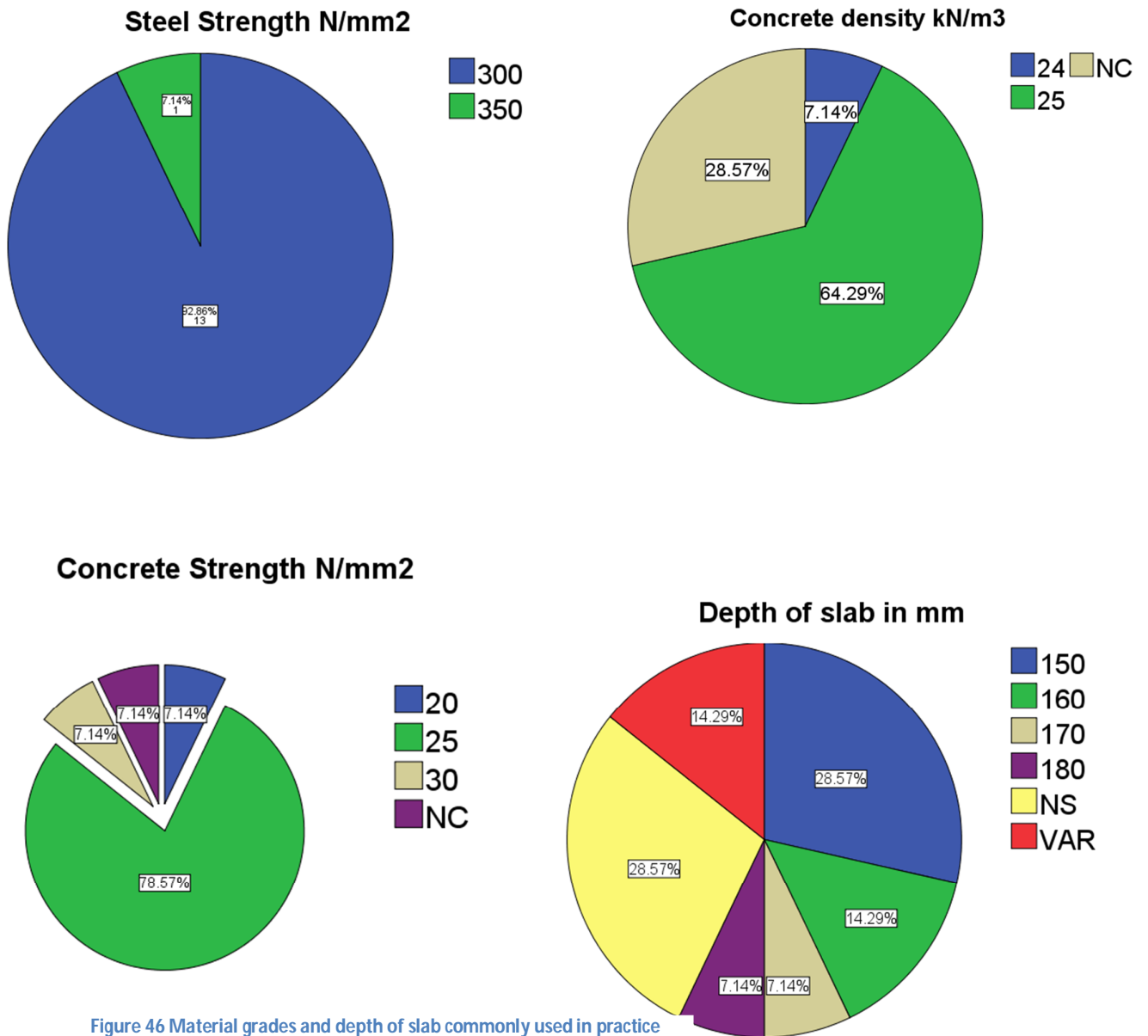


Figure 46 Material grades and depth of slab commonly used in practice

Table 33 Function * Story * As per EBCS * ETABS and SAP * FINITELEMENT * Grade of Designer Cross tabulation

Grade Of Designer	FINITE LEMENT	ETABS and SAP	As per EBCS	Function	Story					
					10	15	2	4	8	9
GE	1			Mixed use				1		
			1	Residential			1			
		1		Residential			1			
ME	NS	NS	NS	Hotel				1		
	1			Hotel				1		
NS			1	Commercial						1
				Mixed use					1	
		1		Nc						1
	NS	NS	NS	Nc			1			
	1			Shop and apartment	1					
PE			1	Residential			1			
PPST		1		Guest house				1		
	NS	NS	NS	Residential				1		
			1	Mixed use		1				

SLAB ACT AS DIAPHRAGM

Slab can act as Diaphragm Constraint which causes all of its constrained joints to move together as a planar diaphragm that is rigid against membrane (in-plane) deformation. This constraint can be used to model concrete floors (or concrete-filled decks) in building structures, which typically have very high in-plane stiffness.

The constraint must apply to at least two joints to have any effect on the model. It is intended to be used on a set of joints that lie in a flat plane. If the joints are not co-planar, the constraint will effectively restrain the joints against out-of-plane (plate) bending, which unrealistically stiffens the structure.

CRITERIA FOR DIAPHRAGM

The criteria for diaphragm is different in different cods even though it is not specified in EBCS, the ACI states diaphragm is Structural member, such as a floor or roof slab, that transmits forces acting in the plane of the member to the vertical elements of the seismic-force-resisting system. And Euro code also describes, in buildings, floors (including the roof) play a very important role in the overall seismic behavior of the structure. They act as horizontal diaphragms that collect and transmit the inertia forces to the vertical structural systems and ensure that those systems act together in resisting the horizontal seismic action. The action of floors as diaphragms is especially relevant in cases of complex and non-uniform layouts of the vertical structural systems, or where systems with different horizontal deformability characteristics are used together (e.g. in dual or mixed systems).

In order the slab to act as diaphragm there is minimum requirement set in codes, for instance in ACI the minimum slab/topping thickness shall be 5.08cm and 63.5mm for cast in

place topping laid on precast beams with temperature and shrinkage reinforcement spaced @ 250mm center to center. Similarly in Euro code the minimum thickness is 7cm.

Slabs which can act as diaphragm are classified in to two parts as ridged and flexible based on different criteria.

Table 34 Criteria for diaphragm rigidity

Diaphragm type	ACI	EC	FEMA
Flexible	Maximum in-plane deflection of the diaphragm (MDD) itself under lateral load is more than two times the average deflection of adjoining vertical elements (ADVC) of the lateral force-resisting system of the associated story under equivalent tributary lateral load. $MDD > 2 * ADVC$.	Other wise	the distance between vertical elements of the seismic force-resisting system does exceeds 12.2m
Ridged	Other wise	The diaphragm is taken as being rigid, if, when it is modeled with its actual in-plane flexibility, its horizontal displacements nowhere exceed those resulting from the rigid diaphragm assumption by more than 10% of the corresponding absolute horizontal displacements in the seismic design situation.	Other wise

This problem is more significant ribbed slab and waffle slabs, one of the common slab types in condominium buildings constructed by our government is precast beam cast in place ribbed slab and hollow block ribbed slab including privet sectors. This type of slab is very sensitive for it doesn't satisfy the diaphragm requirement stated in the cods above. In EBCS it section 3.7.5(5) states the following

Ribbed slab may be treated as solid slab for purpose of analysis provided that the flange of structural topping and transverse ribs has sufficient tensional stiffness. This may be assumed provided:

- a) The rib spacing does not exceed 1.5m
- b) The depth of the rib below the flange does not exceed 4 times its width
- c) The depth of the flange is at least 1/10 of the clear distance between ribs or 50mm whichever is greater
- d) Transverse ribs are provided at clear spacing not exceeding 10 times the overall depth of the slab

The minimum flange thickness of 50mm may be reduced to 40mm where permanent blocks are incorporated between the ribs.

Based on this irrespective of building height and size and type (precast ribbed slab or cast in situ ribbed slab) in practice most toppings are less than or equal to 60mm and the spacing of minimum reinforcement is greater than 250mm center to center, no one is interested on diaphragm effect or requirement. To check these ideas sample ribbed slab buildings G+8 and G+4 are analyzed using ETABS V 9.7.4 for different thickness of topping as presented below:

Table 35 building parameters

Parameters	Building type	
	G+8	G+4
Column size	400x400x45 (DxWxd') in mm	600x600x60 (DxWxd') in mm
Beam size	300x600x35 (DxWxd') in mm	300x600x35 (DxWxd') in mm
Rib size	270x70x15 (DxWxd') in mm	270x70x15 (DxWxd') in mm
Materials	C-25 and S-300	C-25 and S-300
Topping thickness	4,5,6,7,8 in cm	4,5,6,7,8 in cm
Rib spacing	40cm	40cm
Story height	3.2 m	3.2 m
Earth quake zone	IV (Sd(T1)= 0.0753)	IV(Sd(T1)= 0.0974)
Diaphragm type	Flexible (diaphragm not assigned) and ridged(diaphragm assigned)	Flexible (diaphragm not assigned) and ridged(diaphragm assigned)

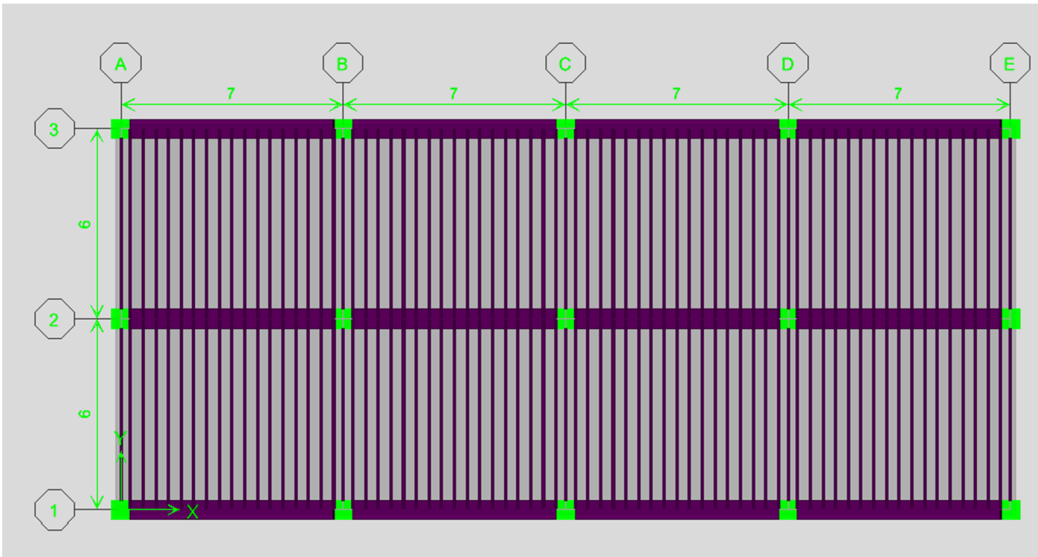


Figure 47 Typical floor plan

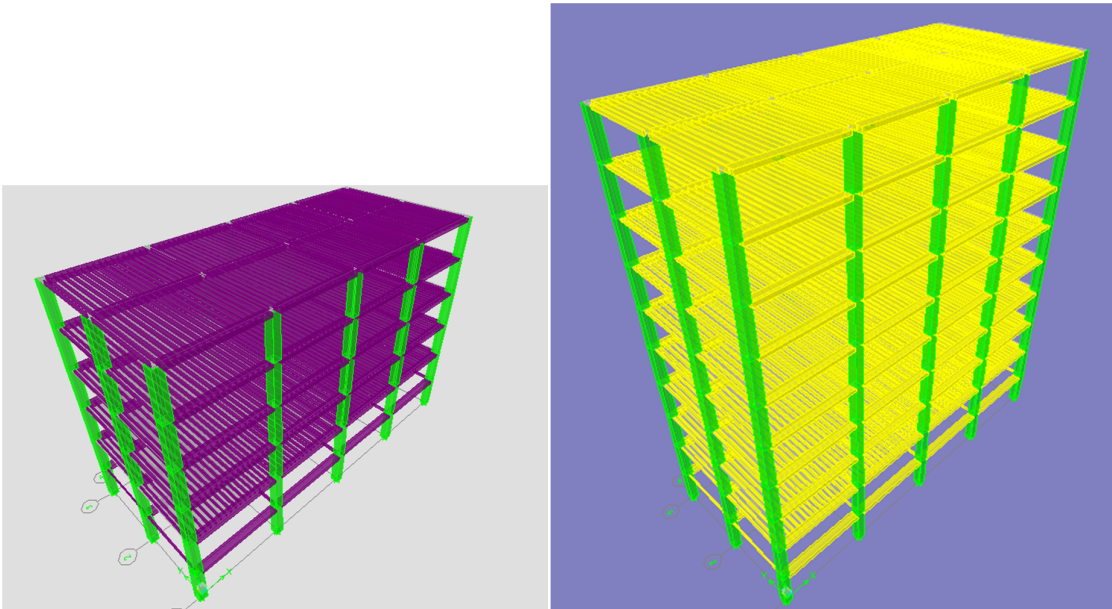


Figure 48 3D model of G+4 and G+8 buildings

Table 36 Deflection increment

Topping thickness (cm)	Deflection increment, flexible to ridged diaphragm ration (%)		
	G+8	G+4	Limit
4	13.715	13.88401	10
5	13.148	12.93997	10
6	12.696	12.35328	10
7	12.286	11.80526	10
8	11.91	11.53897	10

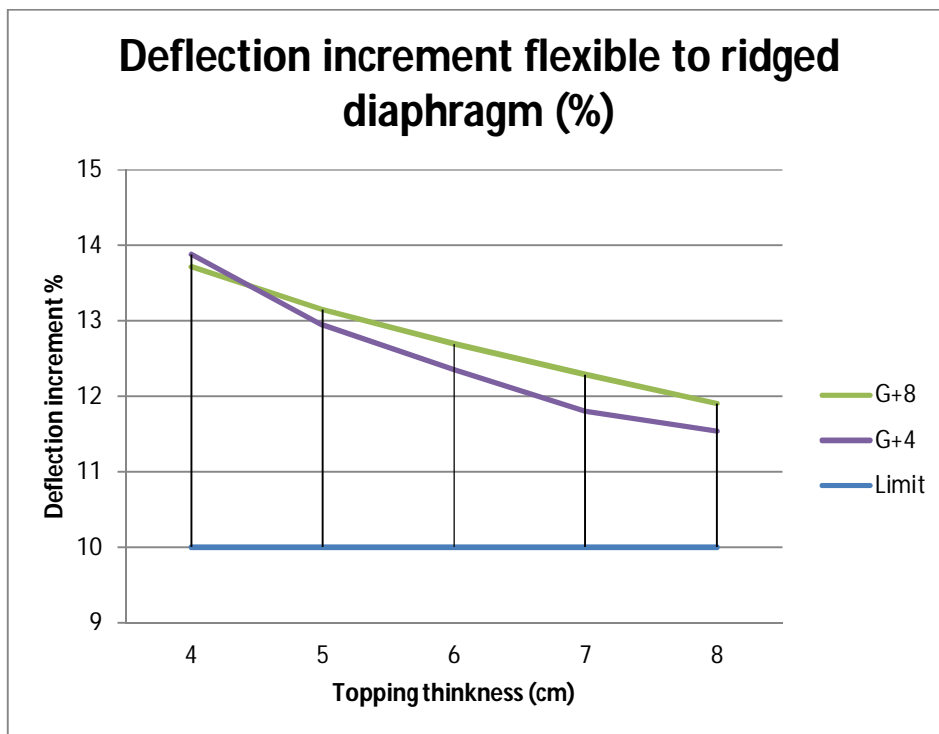


Figure 49 slab diaphragm effect in building

This graph shows the displacement of the building for thicknesses of topping slab 4cm to 8 cm horizontal displacements exceeds those resulting from the rigid diaphragm assumption by more than 10% of the corresponding absolute horizontal displacements in this seismic design situation, indicates responses could be underestimated during analysis and possibly will show the way to both local and global failure of the building. A modeled building at early design stage is known such condition is not satisfied the building shall not be modeled as flexible diaphragm rather ridged diaphragm.

6) CONCLUSION

Different methods of assessment and evaluation are used to find the strength and weakness of the local slab analysis and design practice of our country particularly in Addis Ababa and Mekelle. Considering the stake holders participating in this situation codes are evaluated, questioners collected and design report documents are assessed pertinent to each stake holders.

Although, the government play undeniable role creating laws and codes and puts a great effort in implementing them. We can't end that the practice on the ground is perfect, but rather full of headaches because the practice is a contribution of stake holders. Hence, we can conclude the general practice of analysis of structures particularly slab, as described and presented above is not to the standard and well organized and controlled. The reasons can be summarized.

1. The codes lack consistency for these are not derived from one code and include unclear part which lack of commentary and supporting publications and references. Moreover, it stays long without updating revisions and never incorporates customer fed back. Some parts of the code are difficult to verify and use because it not clear form where those are referenced. For instant almost all respondents believe coefficient method of table A.1 of EBCS is elastic analysis which is completely wrong besides the depth requirement of slab is relatively lesser(though it satisfies the deflection criteria) as compare to other codes for lesser spans up to 4m but extremely low for large spans more than 4m. the other very critical which I believe forgotten or I can say neglected is diaphragm requirement of ribbed and precast slabs, they use more than 6 stories with topping depth of 5cm which is completely out of the reality and danger as shown on other codes. The other very ambiguous issue is the coefficient method of analysis stated in EBCS 2 table A.1 it was derived for modified yield line which is safe but on virtue of failure, I e. plastic analysis which economical but not conservative, on the contrast almost all respondents believe this analysis method is based on elastic analysis and conservative and uneconomical which give them over confidence.
2. Weakness in controlling and applying the proclamation and codes by government body. which shows
 - a. Lack of Creating awareness to public and professionals and shortage resources for practicing engineers and make as one of the criteria for certification. Recording failures and posting in medias
 - b. Shortage of resources and qualified professionals in municipality and unable to use the advantage given by the proclamation.
 - c. Negligence, deliberately or unknowingly to check designs by municipal engineers
 - d. Participation of illegally in design and checking of plans.
 - e. etc
3. Lack of awareness of clients about the design and its consequence.
 - a. They only focus on cost of design; they prefer very low cost neglecting the designer.
 - b. These is misunderstanding in identifying practiced, qualified and experienced professional
 - c. Lack of awareness of the consequence of design performed by unqualified, inexperienced professional. Most say "there is no building failed".
 - d. Etc
4. Lack of practicing engineers to updating to latest knowledge and information, and weak in fighting illegal designers who break the market.

5. Shortage of practicing engineers in teaching learning process and unable to cover the courses in time. And providing different methods of design and code, some teach according to ACI, some according to Indian standard and the like.

Due to the result of poor analysis and design and its control together with poor construction quality, buildings have been failing. One of the practical examples is building shown in figure 73. Most of the building failures specially slab area changed or covered as soon as possible. Most the respondents agree that they experience slab failure. Hence, we can finally conclude that the practice of analysis and design of slab and other structures is not in good position and leads to a very visible danger to occupants and stake holders including government.

7) RECOMMENDATIONS

As presented in conclusion the main problems of slab analysis and design practice in Ethiopia appreciating the good deeds are, lack of awareness on proclamation, code publication shortage and clarity lack of the code , supporting material unavailability, inconsistency in teaching-learning process, market breakage by illegal inexperienced and unqualified designers, low cost for design and analysis, client lack of awareness and strength lack of government bodies in implementing the codes and proclamations. These are the least but not last, hence, to tackle this challenge I recommended generally the following ways.

- a) Proclamations and codes shall be revised and shall be prepared form well organized international code with reference or supporting documents and commentary. It shall be made available both in soft and hard copy throughout the country. Sufficient awareness creation to public, government bodies and practicing engineers and stake holders in general shall be made on the new code and this as criteria for certification.
- b) Initiate and support production of supporting books, software, researches, and discussion webs and blogs.
- c) Create body of or part of government bodies who terrace failures (building or any structure failure) and announce to public using media because these are good teachers and help to share experiences to public as whole.
- d) Make consistence curricula and teaching materials though out the country universities and create chance to share their experience and resources.
- e) Enforce municipalities with well qualified and experienced professionals and enhance the controlling mechanism and criteria.
- f) Give value to the professional ethics.
- g) Staged professional examinations.
- h) Control the market systematical by the government.
- i) Etc.

As expressed in the data analysis, most engineers are not willing to reading of latest books and codes, hence, I recommend them to read and enhance their awareness and knowledge using different multimedia and references. And should care special in computing depth of slab more than 6m which is sensitive to aggregate, type reinforcement, span and concrete grade and shall check the deflection and crack width of the slab. Moreover, they should check diaphragm requirement specially ribbed and precast slabs prior to final design. Care shall be taken when using finite element packages, because these underestimates the deflection of the slab as shown in table 25 of this research , moreover, these differs in analysis assumption and detailing with conventional design methods.

Professional ethics is a key element in engineering because most engineering projects are costly and give service to large population, starting from residence to complex mega projects. All the stake holders shall work together and enforce their system to create behavioral change (good professional ethics) fight ethics failure. But shall revise and evaluate their method and policy to see current practice and change future behavioral change which shall be continued to get ultimate goal.

At last, I recommend to municipal and consultant engineers to use spread sheet developed based on this research, developed for 3 methods, EBCS 2 APPENDEX A, Yield line formula method and Pieper and Martens method. The yield line formula method is very advantageous for it provides uniform

reinforcement in both directions, but it is mathematically correct but could be unsafe. To overcome this 10% increment of moment is sufficient.

Note:-Slabs designed by EBCS coefficient method are not based on elastic method (conservative but un-economical) but rather by plastic method (un-conservative and economical) hence care shall be made in design, detailing and construction.

SLAB DESIGN SPREAD SHEET		
1	EBCS 2 APPNEDX A	Non-Conservative
2	Yield line method	Non-Conservative Add 10%
3	Pieper and Martens	Conservative
4	Verification of Yield line M. for UDL & I pa	
5	Verification of Yield line M. for UDL & I pb	
6	Verification of Yield line M. for UDL	

Note : Verifications is done as per Practical yield line design book

Figure 50 slab design spread sheet over view (To get this sheet please send request to this mail; mesginagebre@gmail.com. it is free!!!)

At last I recommend using this document as helpful martial for it simplifies and clarifies the parts of the code in simple, manageable and reasoned way.

FURTHER RESEARCH

1. Software development on alternative method of analysis.
2. Effect of deflection of large span slabs
3. Effect of slab modeling using finite element method supported by column and beam.
4. Slab Diaphragm effect on buildings to seismic effect
5. Effect of slab irregularity on building stiffness
6. Partition load analysis
7. Design of slab on flexible beams

Etc.

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9) APPENDIX I QUESTIONERS

ADDIS ABABA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

STRUCTURAL ENGINEERING CHAIR

IN PARTIAL FULFILMENT OF THE REQUIRMENT FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

(Structural engineering)

ADVISOR: DR. ADIL ZEKARIA

BY: MESGINA GEBREEGZIABIHER

Questioner for consultant engineers:

Assessment and evaluation of slab analysis and design in Ethiopia (particularly in Addis Ababa and Mekelle)

1. Professional Grade: _____
2. Year of graduation: _____
3. General years of experience: _____
4. Particular years of experience on building design: _____
5. Grade of your consulting office _____
6. Do you know the Ethiopian Building Proclamation No. 624/2009 and 243/2011??
 - a) Yes
 - b) No
 - c) No comment
7. The benefits of the code is harmonizing of professional practice and ensure of appropriate level of safety, health and economy, do you think these benefits are on the ground?
 - a) Yes
 - b) No
 - c) No comment
8. It has been assumed during drafting of the code, the design is performed by appropriately qualified registered structural or civil engineers, and construction is done based on appropriately qualified supervisors. Do you think this is actually happen?
 - a) Yes
 - b) No
 - c) No comment
9. In EBCS 1 section 1.1.1(6) states for information not stated in EBCS can be used from euro code, have you refer euro codes, have you ever use euro codes as supporting cods?
 - a) Yes
 - b) No
 - c) No comment

10. Have you ever read all the codes in detail specially slab design and analysis?
- Yes
 - No
 - No comment
11. Do you think all the codes above are easily understandable?
- Easy (user friendly)
 - Medium
 - Complex
 - No comment
12. Do you think the code includes all the minimum possible information?
- Yes
 - No
 - No comment
13. Which part of the code is Unclear or too complex to under stand
-
14. Which parts of the code have incomplete information?
-
15. Do you believe our codes are fully applied and implemented in day to day design?
- Yes, it is fully applied and implemented
 - Yes, it is partially applied and implemented
 - No ,completely it is not applied and implemented
 - No comment
16. Have you ever refer to other codes in slab design?
- BS,
 - EC,
 - IS
 - Others: specify _____
17. In EBCS I there are five category of occupants but category B and D are not completely stated to which building function these belongs, how do you treat buildings not stated in the code?
- Neglect them*
 - Take guess:_____*
 - Take as general _____*
 - Other_____*
18. Do you know partition wall can be treated as imposed (live) load as per our code?
- Yes
 - No
 - Other_____*
Which type:_____
19. Which slab type is commonly designed by your office?
- One way solid slab*
 - Two way solid slab*
 - One way ribbed slab*
 - Two way waffle slab*
 - Flat slab*
20. Which one of these of one way slab types was used?
- Slab supported by two parallel side beams and the two the two parallel sides are free.*
 - Slab supported by four beams but the leegth ratio of larger side to shortest side greater than*
21. Calculating the depth is one task, how you calculate depth of the slab.
- Simply assume depth*
 - Using equation in EBCS*
 - Using other codes span to depth ration*
 - No comment*
22. Is the depth for one way slab calculated using EBCS 2 equation sufficient for both ULS and SLS.
- The depth is excessive*

- b) *The depth Sufficient*
 c) *The depth is sufficient*
 d) *Other: _____*
23. What value of concrete cover do you take in design top and bottom? _____
24. How do you consider partitions in one way slab?
 a) *As equivalent distributed load _____*
 b) *Add as dead load 20% of the total load*
 c) *Use approximate methods such as _____*
 d) *Use as concentrated load*
 e) *No comment*
25. Which concrete grade do you mostly use for slabs in design?
 a) *C20*
 b) *C25*
 c) *C30*
 d) *Other: _____*
Why you select this grade for slabs
26. Which steel grade do you mostly use for slabs in design?
 a) *S300*
 b) *S400*
 c) *S460*
 d) *S500*
 e) *Other: _____*
Why you select this grade for slabs
27. The modulus of elasticity for concrete is only applicable to concrete made of aggregates predominantly composed of quartzite, do you modify it for other aggregate types such as limestone, sand and blast.
 a) *No, I use the same for all materials*
 b) *Yes, I modify it by _____, _____ and _____ amount respectively.*
28. The code specifies the Poisson's ratio any number between 0 and 0.2 can be taken, what value is common in your slab design.
 a) *0*
 b) *0.2*
 c) *Exactly _____*
 d) *It doesn't have any effect in slab design*
29. Do you think Poisson's ratio have effect in one way slab reinforcement,
 a) *Yes*
 b) *No*
30. How much reinforcement do you use in secondary direction?
 a) *20% of main reinforcement*
 b) *30% of main reinforcement*
 c) *10% of main reinforcement*
 d) *Exactly _____*
 e) *Only minimum reinforcement*
 f) *Other _____*
31. What type of loading do you take for design?
 a) *One load combination $1.3DL + 1.6LL$*
 b) *Different combination to get the maximum sag and hog moments*
 c) *Other method: _____*
32. Which method do you use in one way slab analysis?
 a) *Elastic method (moment distribution method)*
 b) *Simplified method*
 c) *Yield line method*
 d) *Other method: _____*
33. Which method of analysis one way slab do you learn in university?
 a) *Elastic method (moment distribution method)*
 b) *Simplified method*
 c) *Yield line method*
 d) *Strip method*
 e) *Other method: _____*

34. Where do you get the simplified method?
- ACI,
 - BS,
 - EC,
 - IS
 - Others: specify _____
35. Depth of span to depth shows the span to depth ration is larger in EBCS 2 than the other codes? Do you think we are on the safe side?
- Yes
 - No
 - Other

Hence, what will be the solution? _____

36. Other codes give a general span to depth ratio for all two way slabs, where as EBCS 2 gives for 2:1 and 1:1 for intermediate interpolation is allowed. Do you think this is advantageous over the other codes?
- Yes
 - No, it is disadvantageous needs more time?
 - Other
37. In calculating the effective depth for slabs carrying partition likely to crack it is recommended as $\beta_a = 150/l_o$, have you ever use this in calculating effective depth?
- Yes, is the depth greater than table 5.1
 - No, then what depth do you take?
 - Other
38. Which method do you use in two way slab analysis?
- Elastic method (moment distribution method)
 - Simplified method
 - Yield line method
 - Strip method
 - Finite element method(SAP and/or ETABS moment counter)
 - Finite element method(SAFE)
 - Finite element method(other)_____
 - Other method: _____
39. Which one of methods gives you minimum reinforcement?
- Elastic method (moment distribution method)
 - Simplified method
 - Yield line method
 - Strip method
 - Finite element method(SAP and/or ETABS moment counter)
 - Finite element method(SAFE)
 - Finite element method(other)_____
 - Other method: _____
40. Have you ever compare the results of some method?
- Yes
 - No
41. Which one of methods does you thicck more safe?
- Elastic method (moment distribution method)
 - Simplified method
 - Yield line method
 - Strip method
 - Finite element method(SAP and/or ETABS moment counter)
 - Finite element method(SAFE)
 - Finite element method(other)_____

Other method: _____

42. In EBCS 2 section A.3.1.(2) states slab analysis method based of coefficients from table A.1 assumes the slab is loaded to single total load uniformly distributed and the partition wall load also can be converted to equivalent uniform load over the area satisfying the condition that the partition load is less than 20% of the total load, How do you treat for partition walls heavier than 20%
- _____

43. In using table A.1. For computing bending moment of two slabs recommends the beams supporting the slab shall have minimum depth in order to be unyielding, have you ever check the minimum depth requirement of the beam?
- Yes
 - No
 - Other
44. The code recommends either to use the moment coefficient in table A.1. Or the equation given A.2 to A.4 do you think these give the same result?
- Yes
 - No
 - Other
45. The code states the reinforcement calculated either for equation A.2 to A.4 and table A.1. Shall be distributed only in the middle strip only and to provide minimum reinforcement at the edges, have you ever apply this?
- Yes
 - No, why? _____
 - Other
46. The code states in using the equations and table A.1, moment redistribution is not recommended do you really understand what it means?
- Yes
 - No,
 - Other
47. In EBCS it provides two methods to resolve the difference in moment at supports, have you ever apply either or both of them in design?
- Yes
 - No,
 - Other
48. In EBCS it provides two methods to resolve the difference in moment at supports and set criteria , where as British code recommends elastic method and no criteria is set, do you think this is advantageous over British standard?
- Yes
 - No,
 - Other
49. Do you think the method set in EBCS is time saving and economical method?
- Yes
 - No,
 - Other
50. In calculating the effective depth for slabs with normal load and carrying partition likely to crack it is recommended as $d_{eff} = \alpha a$ as per table 5.1 and $\alpha = 150/l_o$ respectively, assuming S300 it calculated as given below,
- Have you ever use this in calculating effective depth?
 - Yes , is the depth greater than table 5.1
 - No, then what depth do you take?
 - Other
51. Commonly we have two types of cantilever based on loading, one is balcony and the other is verandah? Do you take the same loading or different?
- The same
 - Different
 - Other
52. In cantilever design, some say cantilever beam shall be provided to support cantilever slab even it is design 1m width and some say it doesn't need cantilever beam because already the cantilever is designed as 1m width for all loading case and deflection, which one do you think correct?
- With cantilever beam?
 - Yes ,
 - No,
 - Other
 - Why cantilever beam is needed?
53. Which method design do you use in one way slab design?
- As per the tables and charts given in EBCS 2 part 2

- b) *Using design equation*
 c) *Using finite element method*
 d) *Other method: _____*
54. The design table and chart in EBCS 2 are based on parabolic-rectangular stress block? Have you ever used in design rectangular stress block?
 a) *Yes*
 b) *No*
 c) *Other_____*
55. Do you think the charts and tables in EBCS 2 parts 2 are easy to use and to understand?
 a) *Easy to use and understand*
 b) *Medium*
 c) *Complex to understand and use*
 d) *No comment*
56. Do you really understand moment redistribution and its application?
 d) *Yes*
 e) *No*
 f) *Other_____*
57. Have you ever apply moment redistribution in design of one way slab and two way slabs?
 g) *Yes*
 h) *No*
58. How much percent do you use on redistribution?
 a) *≤10%*
 b) *15%*
 c) *20%*
 d) *25%*
 e) *30%*
 f) *Other: _____*
59. Have you ever check the deflection of the slab?
 a) *Yes*
 b) *No*
 Why? _____
60. In detailing of slabs, do you think EBCS 2 and EBCS 2 part 2 provide sufficient information?
 a) *Yes*
 b) *No*
 c) *Other*
61. If you say No, from where do you gate the method of detailing?
 a) *ACI,*
 b) *BS,*
 c) *EC,*
 d) *IS*
 e) *Others: specify _____*
62. Have you ever calculate anchorage bond length, lap length, hops based on EBCS for design?
 a) *Yes*
 b) *No*
 c) *Other*
63. In designing of ribbed slab EBCS recommended to design as one way solid slab, if the criteria set on EBCS 2 section 3.7.5. (5), how do you analyze ribbed slabs?
 a) *As one way solid slab*
 b) *As ribbed slab*
 c) *Other_____*
64. In EBCS it states how to compute moment for partial fixity which is not stated in any of the above expressed codes? Have you ever use it in practice?
 a) *Yes*
 b) *No*
 c) *Other_____*
65. Which method analysis do you use for irregular slabs analysis?
 a) *By changing to Regular*
 b) *Yield line method*

- c) *Strip method*
 - a) *Using SAFE*
 - d) *Empirical formal*
 - e) *Classical method*
 - f) *Numerical method*
 - g) *Moment couture for SAP or ETABS*
 - h) *Other:_____*
66. Which method analysis do you use for analysis slab with holes?
- a) *As cantilever slabs rounding the hole*
 - b) *Yield line method*
 - c) *Strip method*
 - b) *Using SAFE*
 - d) *Empirical formal*
 - e) *Classical method*
 - f) *Numerical method*
 - g) *Moment couture for SAP or ETABS*
 - h) *Other:_____*
67. Do you think the payment for designing of slabs and other structures is affordable?
- a) *Yes*
 - b) *No*
 - c) *Other_____*
68. As per researches the cost of slabs accounts about 59 % of the building structural cost, do you think your designs are economical?
- a) *Yes*
 - b) *No*
 - c) *Other_____*
69. Do you believe the designs of slab are given in detail in university or do you believe the time given for such course is sufficient?
- a) *Yes*
 - b) *No*
 - c) *Other_____*
70. Have you ever read books and pertinent references to enhance your knowledge and crier?
- a) *frequently*
 - b) *rarely*
 - c) *never*
 - d) *Other_____*
71. Have you ever try to develop software for slab design?
- a) *Yes*
 - b) *No*
 - c) *Other_____*
72. Do municipality engineers check slab design analysis method and design thoroughly?
- a) *Yes*
 - b) *No*
 - c) *Other_____*
73. Have you ever practice slab cracked or deflected excessively?
- a) *Yes*
 - b) *No*
 - c) *Other_____*
74. Have you ever see a slab failed?
- a) *Yes*
 - b) *No*
 - c) *Other_____*
75. What problems do you face in design?

76. What recommendation do you have in the next code preparation?

What recommendation do you have in the teaching and learning process?

ADDIS ABABA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

STRUCTURAL ENGINEERING CHAIR

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

(Structural engineering)

ADVISOR: DR. ADIL ZEKARIA

RESEARCH BY: MESGINA GEBREEGZIABIHER

Questioner for contractor engineers :

Assessment and evaluation of slab analysis and design in Ethiopia (particularly in Addis Ababa and Mekelle)

1. Professional Grade: _____
2. Year of graduation: _____
3. years of experience: _____
4. Do you know the Ethiopian Building Proclamation No. 624/2009 and 243/2011??
 - d) Yes
 - e) No
 - f) No comment
5. Do you know the codes used for slab design?
 - a) Yes
 - b) No
 - c) No comment
6. The benefits of the code is harmonizing of professional practice and ensure of appropriate level of safety, health and economy, do you think these benefits are on the ground?
 - d) Yes
 - e) No
 - f) No comment
7. It has been assumed during drafting of this code, the design is performed by appropriately qualified registered structural or civil engineers, and construction is done based on appropriately qualified supervisors. Do you think this is actually happen?
 - g) Yes
 - h) No
 - i) No comment
8. Do you believe slabs are as designed well?
 - a) Yes
 - b) No
 - c) No comment
9. Does drawings are descriptive?
 - a) Yes
 - b) No
 - c) No comment
10. Do you think slab designs are economical?
 - a) Yes

- b) No
 - c) No comment
11. Do you believe municipality engineers checks slab design analysis method and design thoroughly?
- d) Yes
 - e) No
 - f) Other_____
12. Have you ever practice slab cracked or deflected excessively?
- d) Yes
 - e) No
 - f) Other_____
13. Have you ever see a slab failed?
- d) Yes
 - e) No
 - f) Other_____
14. Do you think all slabs are designed by well qualified experienced engineer?
_____why?_____
15. What problems do you face in construction of slab?
- _____
- _____
- _____
- _____
16. What recommendation do you have in the next code preparation?
- _____
- _____
- _____
- _____
17. What recommendation do you have in the teaching and learning process?
- _____
- _____
- _____
- _____
- _____

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(Structural engineering)

ADVISOR: DR. ADIL ZEKARIA

BY: MESSINA GEBREEGZIABIHER

Questioner for municipality engineer:

Assessment and evaluation of slab analysis and design in Ethiopia (particularly in Addis Ababa and Mekelle)

1. Professional Grade: _____
2. Year of graduation: _____
3. General years of experience: _____
4. Particular years of experience on building design approval: _____
5. Do you know the Ethiopian Building Proclamation No. 624/2009 and 243/2011?
 - g) Yes
 - h) No
 - i) No comment
6. Have you ever implement the above proclamations in checking plans?
 - j) Yes
 - k) No
 - l) No comment
7. Do you have in your office the Ethiopian Building code of standard (EBCS)?
 - a) Yes
 - b) No
 - c) No comment
8. The benefits of the code is harmonizing of professional practice and ensure of appropriate level of safety, health and economy, do you think these benefits are on the ground?
 - g) Yes
 - h) No
 - i) No comment
9. It has been assumed during drafting of this code, the design is performed by appropriately qualified registered structural or civil engineers, and construction is done based on appropriately qualified supervisors. Do you think this is actually happen?
 - j) Yes
 - k) No
 - l) No comment
10. Do you use codes in slab design approval?

- a) Yes
 - b) No
 - c) No comment
11. In EBCS 1 section 1.1.1(6) states for which are not stated in EBCS can be used from euro code, have you refer euro codes, have you ever use euro codes as supporting cods?
- d) Yes
 - e) No
 - f) No comment
12. Do you think all the codes above are easily understandable?
- e) Easy (user friendly)
 - f) Medium
 - g) Complex
 - h) No comment
13. Do you think the code includes all the minimum possible information?
- d) Yes
 - e) No
 - f) No comment
14. Which part of the code is Unclear or too complex to under stand? _____
15. Which parts of the code have incomplete information?
16. Do you believe our codes are fully applied and implemented in day to day design?
- e) Yes, it is fully applied and implemented
 - f) Yes, it is partially applied and implemented
 - g) No ,completely it is not applied and implemented
 - h) No comment
17. In EBCS I there are five category of occupants but category B and D are not completely stated to which building function these belongs, how do you approve the categories not stated in the code?
- e) *Neglect them*
 - f) *Take guess:_____*
 - g) *Take as general:_____*
 - h) *Other_____*
18. Do most consultants have similar method of analysis and design and detailing of slab?
- a) Yes
 - b) No
 - c) No comment
19. Do you believe you as a municipality engineers checks slab design analysis method and design thoroughly?
- g) Yes
 - h) No
 - i) *Other_____*
20. What part of slab analysis, design and detailing are critically checked?
- a) *Depth*
 - b) *Deflection*
 - c) *Method of analysis*
 - d) *Method of design*
 - e) *Minimum and maximum reinforcement*
 - f) *Ductility requirement*
 - g) *Detailing*
 - h) *Other:_____*
21. Do you have a chance to approve and check slabs analyzed by finite element software?

- a) Yes
 - b) No
 - c) No comment
22. If yes, EBCS doesn't have or covered this analysis method, then how do you approved? _____
23. Some engineers take slab moment from SAP or ETABS moment counter, do you think this write?
- a) Yes
 - b) No
 - c) No comment
24. If yes how do you check the assumption of the finite element method such as mesh size support condition etc? _____
25. How do you check if slabs are irregular? _____
26. Have you ever check slab designed based on yield line method or strip method?
- a) Yes
 - b) No
 - c) No comment
27. On the proclamation no. 243/2011 recommends for tasks beyond the capacity of the building officer, he may procure the service of registered professional to perform specific task, have you ever use this act in practice?
- a) Yes
 - b) No
 - c) No comment
- Then how do you check such conditions? _____
28. Do you think slab designs are safe?
- a) Yes
 - b) No
 - c) No comment
29. Do you think slab designs are economical?
- d) Yes
 - e) No
 - f) No comment
30. Do you believe our regulations are strong enough in approving and checking structural design?
- a) Yes
 - b) No
 - c) No comment
31. Have you ever practice slab cracked or deflected excessively?
- g) Yes
 - h) No
 - i) Other _____
32. Have you ever see a slab failed?
- g) Yes
 - h) No
 - i) Other _____
33. Do you think all slabs are designed by well qualified experienced engineer? _____ why? _____
34. What problems do you face in design?

35. What recommendation do you have in the next code preparation?

_____What recommendation do you have in the teaching and learning process?

10) APPENDIX II SLAB SPREAD SHEET

EBCS 2 METHOD

<i>EBCS 2 appendix A method for design of slabs</i>					
Project				Back to main menu	
Owner					
Location					
Panel number					
Date	DD	MM	YY		
Design By					
Revised by					
Consultant					
1 Single load case					
Please fill the highlighted ones					
Material type input					
Concrete grade	C 25				
Steel grade	S 300				
F_{ck}	20.00	F_{cd}	11.33	$F_{ctm}=0.3*f_{ck}^{(2/3)}$	2.21
F_{yk}	300.00	F_{yd}	260.87		

Figure A-4 Division of Slab into Middle and Edge Strips

Slab load					
			Concrete cover(Cc)	15	mm
Effective "d"			Reinforcement bottom(ϕ_b)	8	mm
	d	133.04	Reinforcement Top(ϕ_T)	12	mm
	D	160.00			
			Top rein.	bot. rein.	
Average	d_{act}		133.00	137.00	mm
Dead load					
				Category	Function
				A	Areas for domestic and residential activities
Type(i)	density(kN/m³)	Assumed t	n_i (kN/m²)		
Concrete	25	0.16	4		A1 Floors
Plastering	23	0.025	0.575		A2 Stairs
Cement screed	21	0.03	0.63		A3 Balconies
Floor finish	23	0.02	0.46		B Office areas
		n_{DL}	5.665		C1 Areas with tables, etc.
					C2 Areas with fixed seats,
					Areas without obstacles for moving
					C3 Areas with possible physical activities
					C4
Live load					
Category	live load n_{LL} (kN/m²)	Function of this building			
c5	5	Areas susceptible to large crowds		C5	Areas susceptible to large crowds
				D1	Areas in general retail shops
				D2	Areas in department stores
Partial safety factors					
Condition	γ_{DL}	γ_{LL}			
Servisability limit state	1	1			
Ultimate limit state	1.3	1.6			
Total distributed load					
Partial safety factors					
Condition	$\gamma_{DL}n_{DL}$	$\gamma_{LL}n_{LL}$	$n = \gamma_{DL}n_{DL} + \gamma_{LL}n_{LL}$		
Servisability limit state	5.665	5	10.665 (kN/m ²)		
Ultimate limit state	7.3645	8	15.3645 (kN/m ²)		
Alternativly if the total load n is know				n	(kN/m ²)
			n_D	15.3645	(kN/m ²)

Wall load						
Type of wall	P_a (parallel to "a" or l_x)	Length in m (<"a")	Distance from center of slab (<"b/2")	Equivalent central wall		Select and fill on "Type of wall" Column
	#N/A	✗ 2.23	✗ 1.65	0.000		HBC 20 cm=1
	#N/A	✗ 2.23	✗ 1.65	0.000		HBC 15 cm=2
	#N/A	✗ 2.23	✗ 1.65	0.000		HBC 10 cm=3
	#N/A	✗ 2.23	✗ 1.65	0.000		Brick 6cm=4
	#N/A	✗ 2.74	! 0	0.000		Brick 12.5 cm=5
	#N/A	✗ 2.74	! 0	0.000		Masonry 40cm=6
	#N/A	! 0	! 0	0.000		
	#N/A	! 0	! 0	0.000		
			Total P_a/a	0.000	kN/m	
P_b (parallel to "b" or l_y)(kN/m)	Type of wall	Length in m (<"b-0.2")	Distance from center of slab (<"a/2-0.2")	Equivalent central wall		
	#N/A	✗ 1.48	✗ 2.915	0.000		
	#N/A	✗ 1.48	✗ 2.915	0.000		
	#N/A	✗ 1.48	✗ 2.915	0.000		
	#N/A	✗ 1.48	✗ 2.915	0.000		
	#N/A	✗ 3	✗ 0.6	0.000		
	#N/A	✗ 3	✗ 0.6	0.000		
	#N/A	✗ 3	✗ 0.6	0.000		
	#N/A	✗ 3	✗ 0.6	0.000		
			Total P_b/b	0.000	kN/m	
Alternatively if central wall Known						
	P_a	Fill in this cell.----->>>			kN/m	⊞
	P_b	Fill in this cell.----->>>			kN/m	⊞
Design wall load						
	P_a	0.000 kN/m				
	P_b	0.000 kN/m				

Line load factors	$\alpha = \frac{p_a}{n \times b}$	$\beta = \frac{p_b}{n \times a}$
but if no line loads: $p_a = p_b = 0$, $\alpha = \beta = 0$.		

for a rough estimate line load factors α or β should be less than 0.35.

α β

Hence, You can treat Partition load as distributed load.

Adjusted load (adjusted to account for relatively light line loads)	$n^* = n(1 + \alpha + 2\beta)$ [kN/m ²]
--	---

n^*

Bending moment coefficient formulas

$$\alpha_{yf} = \frac{(24 + 2n_d + 1.5n_d^2)}{1000}$$

$$\alpha_{yf} = \frac{\beta}{(\sqrt{1 + r_3} + \sqrt{1 + r_4})^2}$$

$$\beta = \frac{2}{3} \left\{ 1 - \frac{L_x}{L_y} \sqrt{2\alpha_{yf}} (\sqrt{1 + r_1} + \sqrt{1 + r_2}) \right\}$$

where n_d is the number of discontinuous edges ($0 \leq n_d \leq 4$)
 r_1, r_2, r_3, r_4 are the ratios of negative moment capacity at edges 1 to 4, respectively, to the span moment capacity in the same direction and take values of 4/3 for continuous edges or zero for discontinuous edges.

α_{yf} β α_{xf}

Support moment coefficient				Field moment coefficient	
1	2	3	4	x	y
0.0000	0.045	0.061	0.000	0.045	0.034

$$m = n_d l_x^2 \quad \boxed{553.12} \quad \text{kNm}$$

$$m_i = \alpha_i (g_d + q_d) L_x^2$$

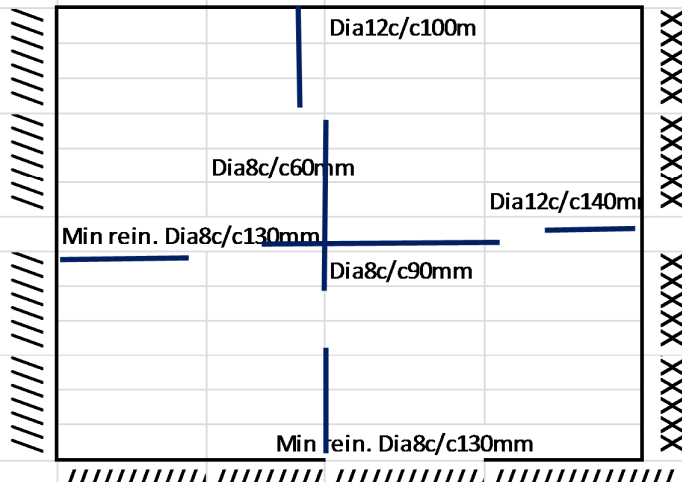
Design

Concrete cover(Cc)	15	mm
Reinforcement bottom(ϕ_b)	8	mm
Reinforcement Top(ϕ_T)	12	mm
Depth of slab(D)	160.00	mm
Aver.eff. Depth (d_{ave})	Top rein.	bot. rein.
	133.00	137.00
		mm

r values	i_1	i_2	i_3	i_4		
	0.00	1.33	1.33	0.00		
Moment	m'_1	m'_2	m'_3	m'_4	m_{xf}	m_{yf}
	0.00	25.07	33.48	0.00	25.11	18.81
M_{RD}	59.08126	59.08126	59.08126	59.08126	62.68846	62.688
Check capacity	OK!!!	OK!!!	OK!!!	OK!!!	OK!!!	OK!!!
K_o	0.0000	0.0709	0.0946	0.0000	0.0669	0.0501
z	133.000	124.085	120.768	133.000	128.369	130.650
Amin[sq.mm]	254.788	254.788	254.788	254.788	262.450	262.450
Ascal [sq.mm]	375	774	1062	375	749.52	551.507
Asfinal [sq.mm]	375	774	1062	375	750	552
ϕ	8	12	12	8	8.00	8.00
S.max [mm]	250	250	250	250	250.00	250.00
S.calc[mm]	134.13	146.07	106.47	134.13	67.06	91.14
S.final [mm]	134.13	146.07	106.47	134.13	67.06	91.14

Use	Min rein. Dia8c/c130mm	Dia12c/c140mm 0mm	Dia12c/c100mm	Min rein. Dia8c/c130mm	Dia8c/c60mm m	Dia8c/c90mm
	Or Min rein. Dia10c/c200mm	Or Dia10c/c100mm	Or Dia10c/c70mm	Or Min rein. Dia10c/c200mm	Or Dia10c/c100mm	Or Dia10c/c140mm

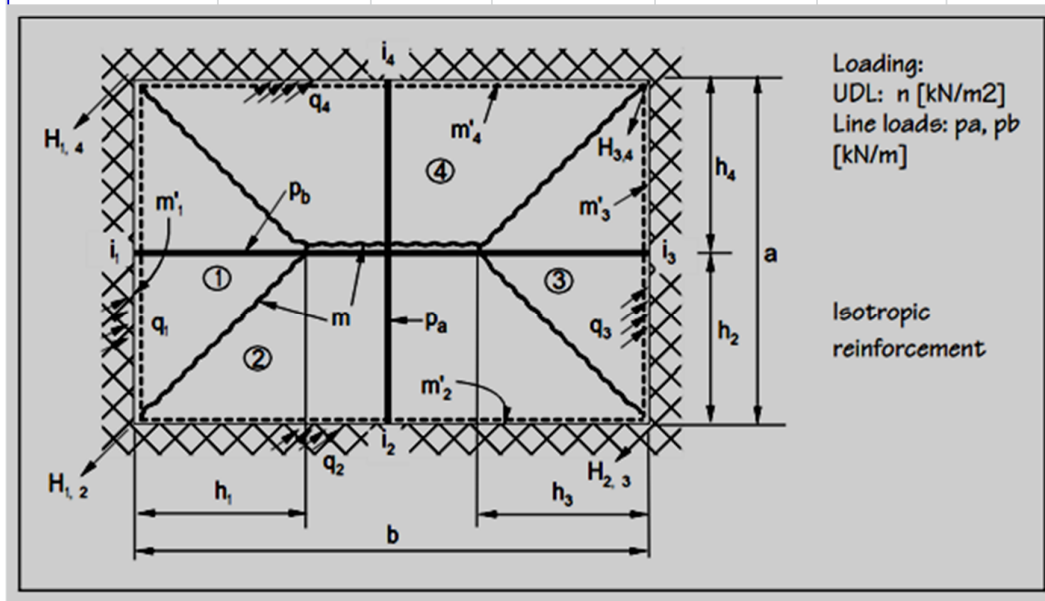
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[Back to top](#)
[Back to main menu](#)

YIELD LINE FORMULA METHOD

Yield line formula method for design of slabs				
Project				Back to main menu
Owner				
Location				
Panel number				
Date	DD		MM	YY
Design By				
Revised by				
Consultant				
1 Single load case 2 Always Add 10% reinforcement 3 10% rule is only applicable to regular slabs and slabs can be modeled as regular slabs				
Please fill the highlighted ones				
Material type input				
Concrete grade	C	25		
Steel grade	S	300		
F_{ck}	20.00	F_{cd}	11.33	$F_{ctm}=0.3*f_{ck}^{(2/3)}$ 2.21
F_{yk}	300.00	F_{yd}	260.87	



Where

- m is the ultimate moment along the yield line (sagging) [kNm/m]
- m' is the ultimate moment along the yield line (hogging) [kNm/m]
- p_a, p_b are the line loads (partitions) [kN/m]
- n is the total ultimate uniformly distributed load, 1.4g_k + 1.6p_k [kN/m²]
- q is the reaction [kN/m]
- a, b, h are the dimensions [m]
- H is the holding down forces at corners [kN]
- i₁, i₂, i₃, i₄ are the fixity, the ratios m'/m for regions 1, 2, 3 and 4.

Type of wall
HBC 20 cm=1
HBC 15 cm=2
HBC 10 cm=3
Brick 6cm=4
Brick 12.5 cm=5
Masonry 40cm=6

Size of slab						
"a"=l _x	6					
"b"=l _y	7					
Wall load calculation						

Wall type	Density of wall	Density of plastering	Wall thickness(m)	Plastering thickness(on e side)	Wall height	Wall load kN/m
1	14	23	0.200	0.025	3	11.85
2	14	23	0.150	0.025	3	9.75
3	14	23	0.100	0.025	3	7.65
4	19	23	0.060	0.025	3	6.87
5	19	23	0.125	0.025	3	10.575
6	27	23	0.400	0.025	3	35.85

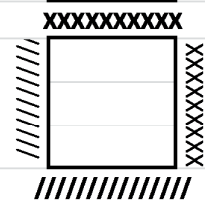
Support condition

Fixity ratios^Q $i_1 = \frac{m'_1}{m}$ $i_2 = \frac{m'_2}{m}$ $i_3 = \frac{m'_3}{m}$ $i_4 = \frac{m'_4}{m}$

Panel Type Case No.= 4

Support number	Fixity
i ₁	0.000
i ₂	0.000
i ₃	1.333
i ₄	1.333

M'/m
1.33
0 to 2



XXXXX -Continuous
 ////////// -Discontinuous

β _a for 2:1	β _a for 1:1	Ratio calc.	β _a calc
30.00	40.00	1.17	38.33

Note :- For slabs of equal side length, the effective depth shall be checked for both directions to consider the support condition.

Slab load					
			Concrete cover(Cc)	15	
Effective "d"			Reinforcement bottom(ϕ_b)	8	
	d	133.04 mm	Reinforcement Top(ϕ_T)	12	
	D	160.00 mm			
Average	d_{act}	Top rein.	bot. rein.		
		133.00	137.00	mm	
Dead load				Category	Function
				A	Areas for domestic and residential activities
Type(i)	density(kN/m³)	Assumed t	n_i (kN/m²)	A1	Floors
Concrete	25	0.16	4	A2	Stairs
Plastering	23	0.025	0.575	A3	Balconies
Cement screed	21	0.03	0.63	B	Office areas
Floor finish	23	0.02	0.46	C1	Areas with tables, etc.
		n_{DL}	5.665	C2	Areas with fixed seats,
				C3	Areas without obstacles for moving
				C4	Areas with possible physical activities
Live load					
Category	live load n_{LL} (kN/m²)	Function of this building			
c5	5	Areas susceptible to large crowds		C5	Areas susceptible to large crowds
				D1	Areas in general retail shops
				D2	Areas in department stores
Partial safety factors					
Condition	γ_{DL}	γ_{LL}			
Servisability limit state	1	1			
Ultimate limit state	1.3	1.6			
Total distributed load					
Partial safety factors					
Condition	$\gamma_{DL}n_{DL}$	$\gamma_{LL}n_{LL}$	$n = \gamma_{DL}n_{DL} + \gamma_{LL}n_{LL}$		
Servisability limit state	5.665	5	10.665 (kN/m ²)		
Ultimate limit state	7.3645	8	15.3645 (kN/m ²)		
Alternativly if the total load n is know				n	(kN/m ²)
			n_D	15.3645	(kN/m ²)

Wall load						
Type of wall	P_a (parallel to "a" or l_x)	Length in m (<"a")	Distance from center of slab (<"b/2")	Equivalent central wall		Select and fill on "Type of wall" Column
	#N/A	✓ 2.23	✓ 1.65	0.000		HBC 20 cm=1
	#N/A	✓ 2.23	✓ 1.65	0.000		HBC 15 cm=2
	#N/A	✓ 2.23	✓ 1.65	0.000		HBC 10 cm=3
	#N/A	✓ 2.23	✓ 1.65	0.000		Brick 6cm=4
	#N/A	✓ 2.74	✓ 0	0.000		Brick 12.5 cm=5
	#N/A	✓ 2.74	✓ 0	0.000		Masonry 40cm=6
	#N/A	✓ 0	✓ 0	0.000		
	#N/A	✓ 0	✓ 0	0.000		
			Total P_a/a	0.000	kN/m	
P_b (parallel to "b" or l_y)(kN/m)	Type of wall	Length in m (<"b-0.2")	Distance from center of slab (<"a/2-0.2")	Equivalent central wall		
	#N/A	✓ 1.48	⚠ 2.915	0.000		
	#N/A	✓ 1.48	⚠ 2.915	0.000		
	#N/A	✓ 1.48	⚠ 2.915	0.000		
	#N/A	✓ 1.48	⚠ 2.915	0.000		
	#N/A	✓ 3	✓ 0.6	0.000		
	#N/A	✓ 3	✓ 0.6	0.000		
	#N/A	✓ 3	✓ 0.6	0.000		
	#N/A	✓ 3	✓ 0.6	0.000		
			Total P_b/b	0.000	kN/m	
Alternatively if central wall Known						
	P_a	Fill in this cell.----->>>>			kN/m	⊞
	P_b	Fill in this cell.----->>>>			kN/m	⊞
Design wall load						
	P_a	0.000 kN/m				
	P_b	0.000 kN/m				

Line load factors	$\alpha = \frac{p_a}{n \times b}$	$\beta = \frac{p_b}{n \times a}$
	but if no line loads: $p_a = p_b = 0$, $\alpha = \beta = 0$.	
for a rough estimate line load factors α or β should be less than 0.35.		
	α <input type="text" value="0.000"/>	β <input type="text" value="0.000"/>
Hence, You can treat Partition load as distributed load.		
Reduced sides ^R	$a_r = \frac{2a}{\sqrt{1+i_2} + \sqrt{1+i_4}}$ [m]	$b_r = \frac{2b}{\sqrt{1+i_1} + \sqrt{1+i_3}}$ [m]
	a_r <input type="text" value="4.75"/> m	
	b_r <input type="text" value="5.54"/> m	
Adjusted load (adjusted to account for relatively light line loads)	$n^* = n(1 + \alpha + 2\beta)$ [kN/m ²]	
	n^* <input type="text" value="15.365"/> (kN/m ²)	
Adjusted reduced side	$b_r^* = b_r \sqrt{\frac{1 + \alpha + 2\beta}{1 + 3\beta}}$ [m]	
	b_r^* <input type="text" value="5.54"/> m	
Design moment ^S	$m = \frac{n^* \times a_r \times b_r^*}{8 \left(1 + \frac{b_r^*}{a_r} + \frac{a_r}{b_r^*} \right)}$ [kNm/m]	
	m <input type="text" value="16.70"/> kNm	

Check for dimensions

Dimensions

h_i

$$h_1 = \sqrt{\frac{6(1+i_1)}{n(1+3\beta)}} \frac{m}{n} \quad [m]$$

$$h_3 = \sqrt{\frac{6(1+i_3)}{n(1+3\beta)}} \frac{m}{n} \quad [m]$$

$$h_2 = \frac{a_r}{2} \sqrt{1+i_2} \quad [m]$$

$$h_4 = \frac{a_r}{2} \sqrt{1+i_4} \quad [m]$$

h_1	2.55	m
-------	------	---

h_3	3.90	m
-------	------	---

h_2	2.37	m
-------	------	---

h_4	3.63	m
-------	------	---

Check if $(h_1+h_3) < b$

OK!!!

Check if $(h_2+h_4) < a$

OK!!!

Reactions^T

$$q_1 = 4m \left(\frac{1}{a_r} + \frac{1}{b_r} \right) \times \sqrt{1+i_1} \quad [kN/m]$$

$$q_3 = 4m \left(\frac{1}{a_r} + \frac{1}{b_r} \right) \times \sqrt{1+i_3} \quad [kN/m]$$

$$q_2 = 4m \left(\frac{1}{a_r} + \frac{1}{b_r} \right) \times \sqrt{1+i_2} \quad [kN/m]$$

$$q_4 = 4m \left(\frac{1}{a_r} + \frac{1}{b_r} \right) \times \sqrt{1+i_4} \quad [kN/m]$$

q_1	39.92	kNm
-------	-------	-----

q_3	26.13	kNm
-------	-------	-----

q_2	26.13	kNm
-------	-------	-----

q_4	39.92	kNm
-------	-------	-----

Negative reactions (or holding down forces)

$$H_{1,2} = 2m \sqrt{1+i_1} \times \sqrt{1+i_2} \quad [kN]$$

$$H_{3,4} = 2m \sqrt{1+i_3} \times \sqrt{1+i_4} \quad [kN]$$

$$H_{2,3} = 2m \sqrt{1+i_2} \times \sqrt{1+i_3} \quad [kN]$$

$$H_{1,4} = 2m \sqrt{1+i_1} \times \sqrt{1+i_4} \quad [kN]$$

$H_{1,2}$	33.41	kNm
-----------	-------	-----

$H_{3,4}$	77.95	kNm
-----------	-------	-----

$H_{2,3}$	51.03	kNm
-----------	-------	-----

$H_{1,4}$	51.03	kNm
-----------	-------	-----

NB These reactions apply only to slabs supported on four sides without line loads. Where there are line loads use engineering judgement to determine reactions (- the full theory is very involved!)

Pieper and Martens method for design of slabs

Project				Back to main menu
Owner				
Location				
Panel number				
Date	DD	MM	YY	
Design By				
Revised by				
Consultant				

- 1 Single load case
- 2 Always Add 10% reinforcement
- 3 10% rule is only applicable to regular slabs and slabs can be modeled as regular slabs

Please fill the highlighted ones

Material type input

Concrete grade	C 25
Steel grade	S 300

F_{ck}	20.00	F_{cd}	11.33	$\alpha_{tm}=0.3*f_{ck}(2/$	2.21
F_{yk}	300.00	F_{yd}	260.87		

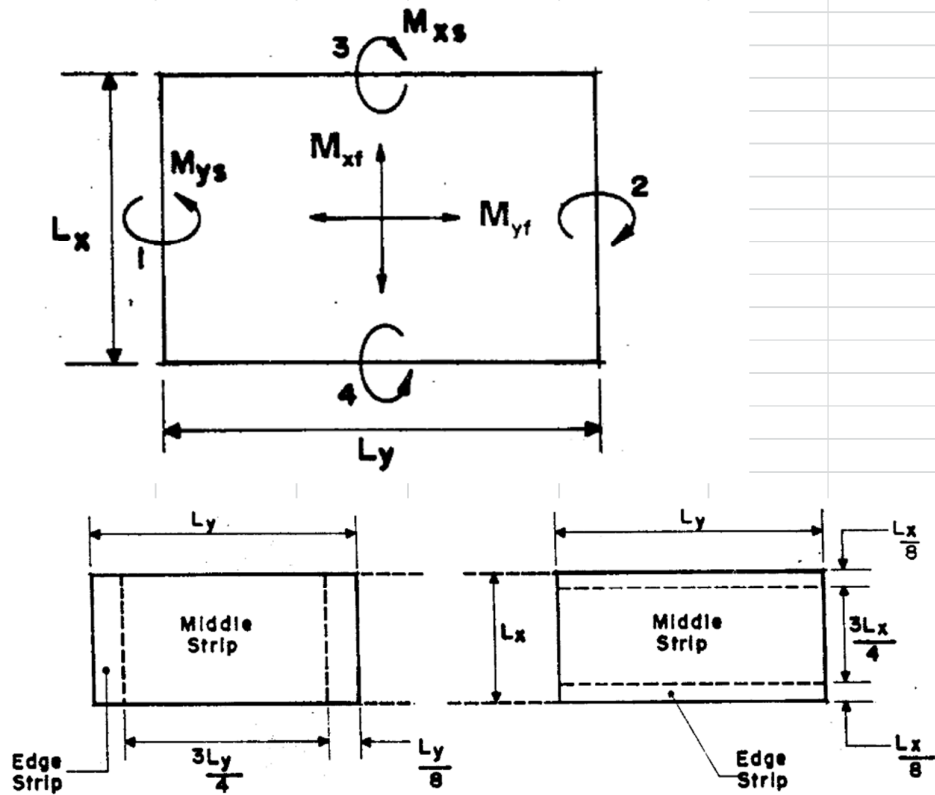


Figure A-4 Division of Slab into Middle and Edge Strips

Slab load					
			Concrete cover(Cc)	15	mm
Effective "d"			Reinforcement bottom(ϕ_b)	8	mm
	d	133.04	Reinforcement Top(ϕ_T)	12	mm
	D	160.00			
			Top rein.	bot. rein.	
Average	d_{act}		133.00	137.00	mm
Dead load				Category	Function
				A	Areas for domestic and residential activities
Type(i)	density(kN/m³)	Assumed t	n_i (kN/m²)	A1	Floors
Concrete	25	0.16	4	A2	Stairs
Plastering	23	0.025	0.575	A3	Balconies
Cement screed	21	0.03	0.63	B	Office areas
Floor finish	23	0.02	0.46	C1	Areas with tables, etc.
		n_{DL}	5.665	C2	Areas with fixed seats,
				C3	Areas without obstacles for moving
				C4	Areas with possible physical activities
Live load					
Category	live load n_{LL} (kN/m²)	Function of this building			
c5	5	Areas susceptible to large crowds		C5	Areas susceptible to large crowds
				D1	Areas in general retail shops
				D2	Areas in department stores
Partial safety factors					
Condition	γ_{DL}	γ_{LL}			
Serviceability limit state	1	1			
Ultimate limit state	1.4	1.6			
Total distributed load					
Partial safety factors					
Condition	$\gamma_{DL}n_{DL}$	$\gamma_{LL}n_{LL}$	$n = \gamma_{DL}n_{DL} + \gamma_{LL}n_{LL}$		
Serviceability limit state	5.665	5	10.665 (kN/m ²)		
Ultimate limit state	7.931	8	15.931 (kN/m ²)		
Alternatively if the total load n is known				n	(kN/m ²)
			n_D	10.665	(kN/m ²)

Line load factors	$\alpha = \frac{p_a}{n \times b}$	$\beta = \frac{p_b}{n \times a}$
but if no line loads: $p_a = p_b = 0$, $\alpha = \beta = 0$.		

for a rough estimate line load factors α or β should be less than 0.35.

α β

Hence, You can treat Partition load as distributed load.

Adjusted load (adjusted to account for relatively light line loads)	$n^* = n(1 + \alpha + 2\beta)$ [kN/m ²]
--	---

n^*

Bending moment coefficient formulas

$$m_{fx} = \frac{ql_x^2}{f_x} \quad \text{and} \quad m_{fy} = \frac{ql_y^2}{f_y}$$

$$m_{s_0} = -\frac{ql_x^2}{s_x} \quad \text{or} \quad m_{s_0} = -\frac{ql_y^2}{s_y}$$

moment with neighbor panel

$$m_s = \begin{cases} \frac{m_{s_{01}} + m_{s_{02}}}{2} \geq 0.75 \min m_{s_0} & \text{for } l_1 : l_2 < 5 : 1, \\ \min m_{s_0} & \text{for } l_1 : l_2 > 5 : 1, \end{cases}$$

	below l_y/l_x	above l_y/l_x	actual l_y/l_x
	1.10	1.20	1.17
f_x	<input type="text" value="27.300"/>		
f_y	<input type="text" value="34.10"/>		
s_x	<input type="text" value="12.700"/>		
s_y	<input type="text" value="13.6"/>		

Support moment coefficient				Field moment coefficient	
1	2	3	4	x	y
<input type="text" value="0.0000"/>	<input type="text" value="12.700"/>	<input type="text" value="13.600"/>	<input type="text" value="0.000"/>	<input type="text" value="27.300"/>	<input type="text" value="34.100"/>

$m = n_d l_x^2$ kNm

Design						
Concrete cover(Cc)	15 mm					
Reinforcement bottom(ϕ_b)	8 mm					
Reinforcement Top(ϕ_T)	12 mm					
Depth of slab(D)	160.00 mm					
Aver. eff. Depth (d_{ave})	Top rein.	bot. rein.				
	133.00	137.00			mm	
r values	i_1	i_2	i_3	i_4		
	0.00	1.20	1.20	0.00		
Moment	m'_1	m'_2	m'_3	m'_4	m_{xf}	m_{yf}
	0.00	30.23	28.23	0.00	14.06	11.26
M_{RD}	59.08126	59.08126	59.08126	59.08126	62.68846	62.688
Check capacity	OK!!!	OK!!!	OK!!!	OK!!!	OK!!!	OK!!!
K_o	0.0000	0.0855	0.0798	0.0000	0.0375	0.0300
z	133.000	122.074	122.863	133.000	132.311	133.273
Amin[sq.mm]	254.788	254.788	254.788	254.788	262.450	262.450
Ascal [sq.mm]	204	949	880	204	407.25	323.688
Asfinal [sq.mm]	255	949	880	255	407	324
ϕ	8	12	12	8	8.00	8.00
S.max [mm]	250	250	250	250	250.00	250.00
S.calc[mm]	197.28	119.19	128.47	197.28	123.43	155.29
S.final [mm]	197.28	119.19	128.47	197.28	123.43	155.29
Use	Min rein. Dia8c/c190mm	Dia12c/c11 0mm	Dia12c/c120mm	Min rein. Dia8c/c190mm	Dia8c/c120m m	Dia8c/c150mm
	Or Min rein. Dia10c/c250m m	Or Dia10c/c80 mm	Or Dia10c/c80mm	Or Min rein. Dia10c/c250mm	Or Dia10c/c190 mm	Or Dia10c/c240mm
XXXXXXXXX XXXXXX) XXXXXXXXXXXX XXXXXXXXXXXXX						
						Back to top
						Back to main menu

11) APPENDEK III

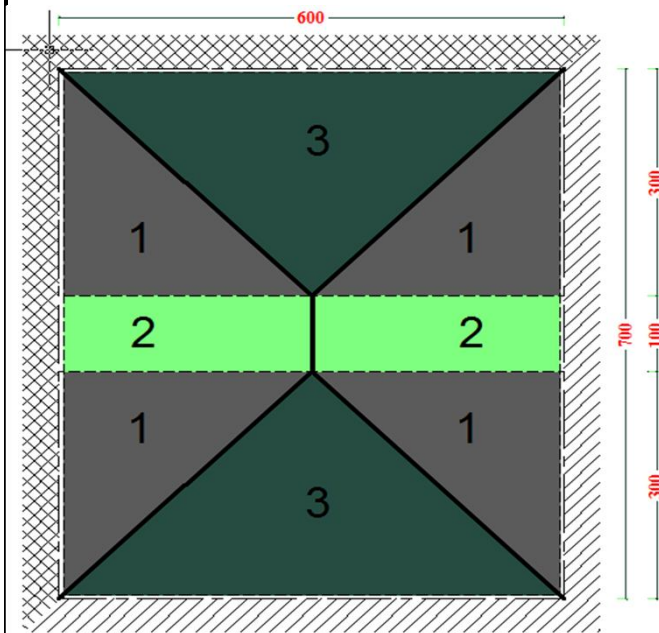
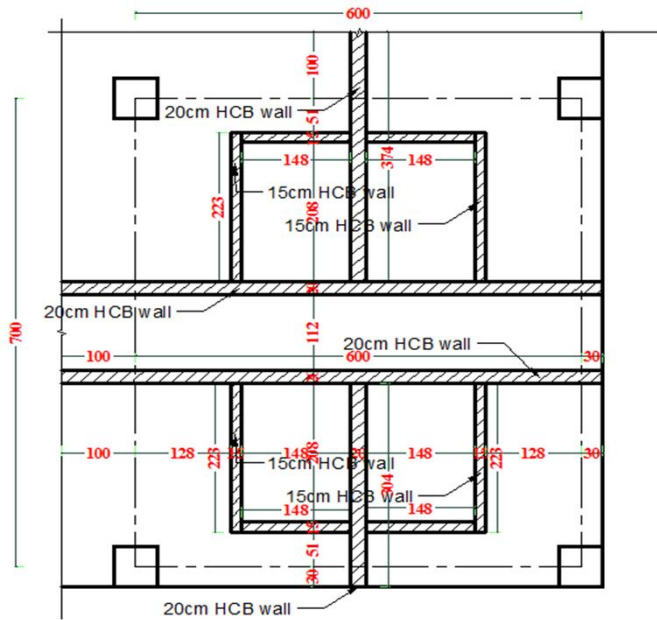
Partition wall verification
Using virtual work method

Partition load analysis comparison using vetual work method (modeling as line load and distributed load)

Slab cut from hotel building with high partition load concentration.

Note :-

- Slab depth **16.00** cm
- Live load **5.00** kN/m²
- L_x **6.00** m
- L_y **7.00** m
- Concrete **C-25**
- Steel grad **S-300**
- Assume isotropic reinforcement in both direction
- 45° yield line bisects the slab



Load	Volume/area	Density(kN/m ³)	Weight	Unit
Self-load slab	0.16	25	4	kN/m ²
Cement screed	0.03	21	0.63	kN/m ²
Floor finish	0.02	23	0.46	kN/m ²
Plastering	0.025	23	0.575	kN/m ²
			5.665	kN/m ²
20cm HCB wall				
Wall (20cm thick and 3m high)	0.6	14	8.4	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			11.85	kN/m
15cm HCB wall				
Wall (15cm thick and 3m high)	0.45	14	6.3	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			9.75	kN/m

Load combination	DEAD LOAD	LIVE LOAD	1.3DL+1.6LL	Unit
SINGLE LOAD CASE	5.665	5.00	15.36	kN/m ²
20cm HCB wall	11.85		15.41	kN/m
15cm HCB wall	9.75		12.68	kN/m

Zone	N	Area(A=7x6)(m ²)	w=N/A (kN/m ²)
HCB			
15cm			
(12.675x4x0.84)	42.588	42	1.01
(12.675x4x1.48)	75.036	42	1.79
(12.675x2x1.39)	35.2365	42	0.84
20cm			
(15.405x4x3)	184.86	42	4.40
(15.405x4x2.74)	168.8388	42	4.02
Total			12.06

Total distributed load

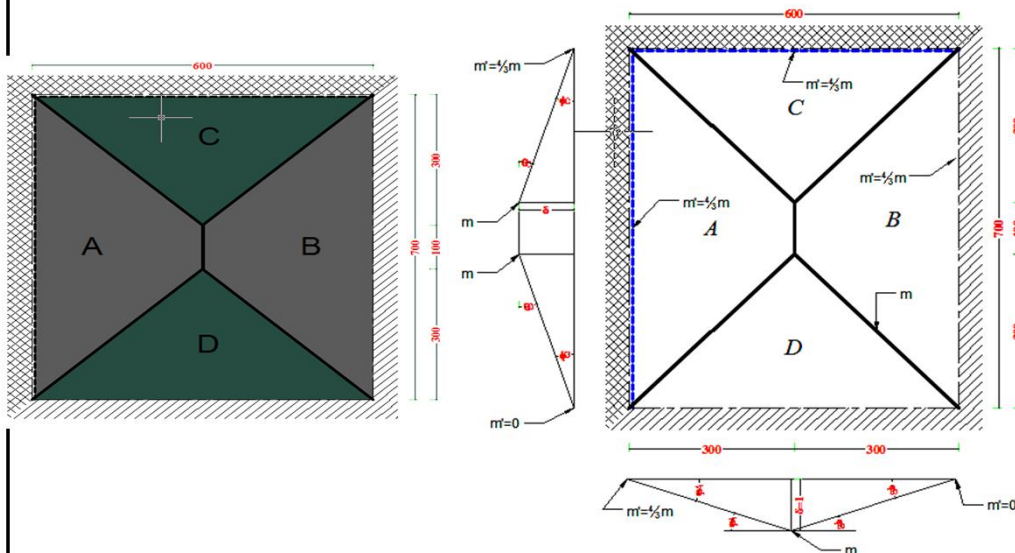
$$A+B = 34.90 \text{ kN/m}^2$$

1.4865

Percent of partition load

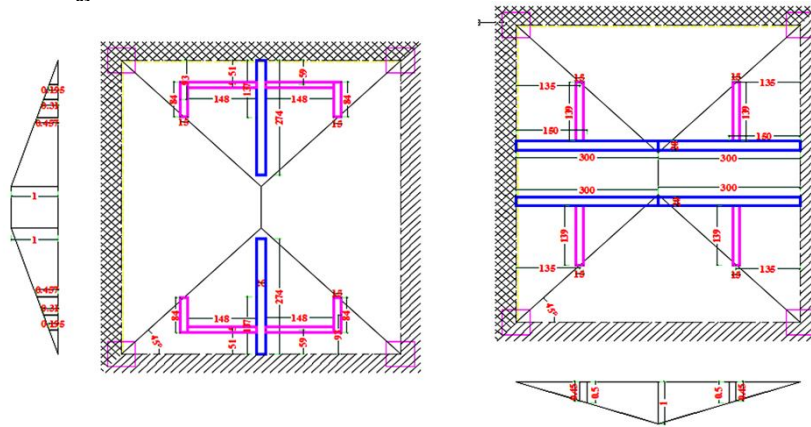
34.56%

Dissipation of internal energy



Zone	Bending moment on yield lines in(k) (x m)	l(m)	θ (radian)	$D=k*I*\theta$ (xm in kNm)
A				
Negative($m'=4m/3$)	1.33	7.00	0.33	3.11
Positive(m)	1.00	7.00	0.33	2.33
B				
Negative($m'=4m/3$)	0.00	7.00	0.33	0.00
Positive(m)	1.00	7.00	0.33	2.33
C				
Negative($m'=4m/3$)	1.33	6.00	0.33	2.67
Positive(m)	1.00	6.00	0.33	2.00
D				
Negative($m'=4m/3$)	0.00	6.00	0.33	0.00
Positive(m)	1.00	6.00	0.33	2.00
Total				14.44

Exerted energy



Zone	N	δ	$E=N*\delta$ (in kNm)
Distributed load			
1-(34.91x6x6)	1,256.41	0.33	418.80
2-(34.91x1x6)	209.40	0.50	30.72
Total			449.52

Equating internal and external energy

$$E = D$$

$D=\Sigma(k*I*\theta)$ (xm in kNm)	$E=\Sigma(N*\delta)$ (in kNm)	$m=E/(\Sigma(k*I*\theta))$ (in kNm)	$m'=4m/3$ (in kNm)
14.44	449.52	31.121	41.494

Partition load analysis comparison using virtual work method (modeling as line load and distributed load)

Slab cut from hotel building with high partition load concentration.

Note :-

- Slab depth

16.00	cm
-------	----
- Live load

5.00	kN/m ²
------	-------------------
- L_x

6.00	m
------	---
- L_y

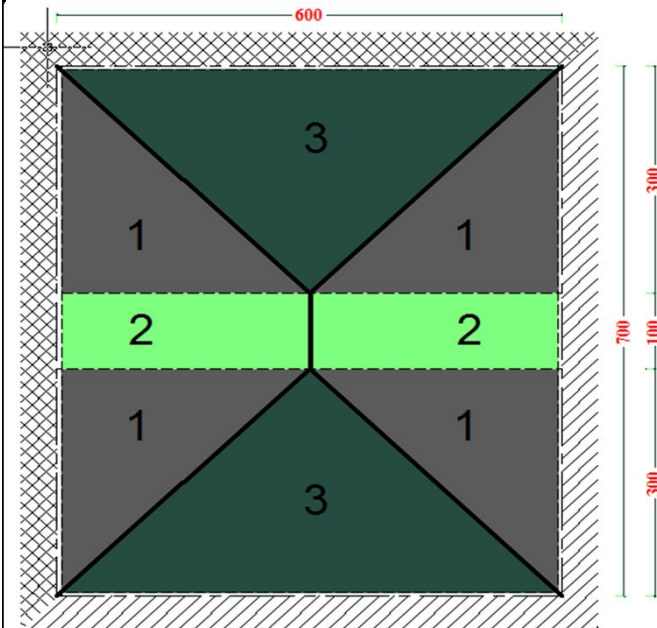
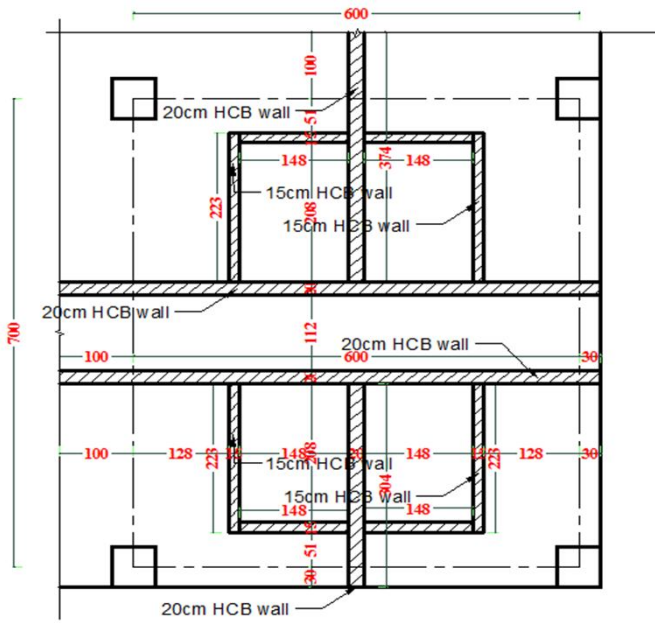
7.00	m
------	---
- Concrete

C-25

- Steel grade

S-300

- Assume isotropic reinforcement in both direction
- 45° yield line bisects the slab



Load	Volume/area	Density(kN/m ³)	Weight	Unit
Self-load slab	0.16	25	4	kN/m ²
Cement screed	0.03	21	0.63	kN/m ²
Floor finish	0.02	23	0.46	kN/m ²
Plastering	0.025	23	0.575	kN/m ²
			5.665	kN/m ²
20cm HCB wall				
Wall (20cm thick and 3m high)	0.6	14	8.4	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			11.85	kN/m
15cm HCB wall				
Wall (15cm thick and 3m high)	0.45	14	6.3	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			9.75	kN/m

Load combination	DEAD LOAD	LIVE LOAD	1.3DL+1.6LL	Unit
SINGLE LOAD CASE	5.665	5.00	15.36	kN/m ²
20cm HCB wall	11.85		15.41	kN/m
15cm HCB wall	9.75		12.68	kN/m

Zone	N	Area(A=7x6)(m ²)	w=N/A (kN/m ²)
HCB			
15cm			
(12.675x4x1.48)	75.036	42	1.79
(12.675x2x1.39)	35.2365	42	0.84
20cm			
(15.405x4x3)	184.86	42	4.40
(15.405x4x2.74)	168.8388	42	4.02
Total			11.05

Total distributed load

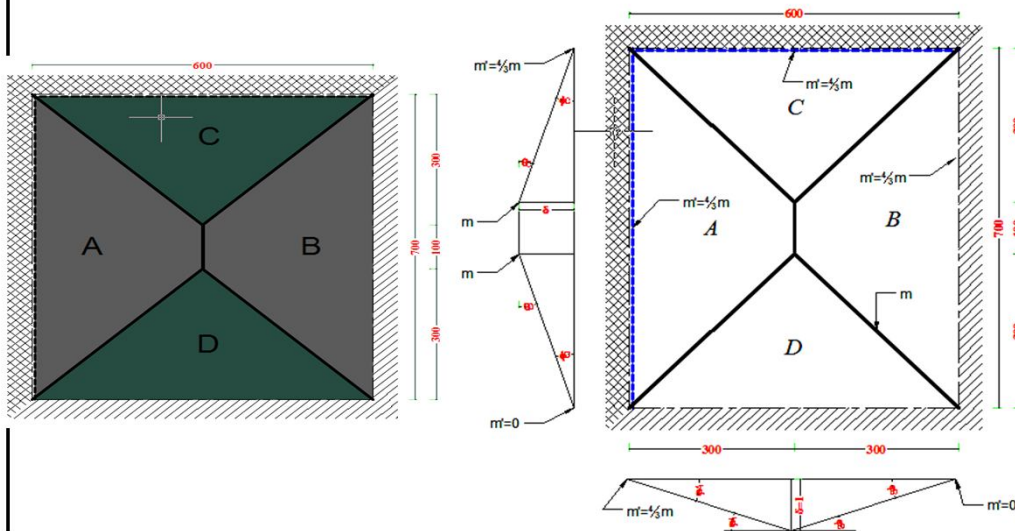
$$A+B = \boxed{33.73} \text{ kN/m}^2$$

1.4765

Percent of partition load

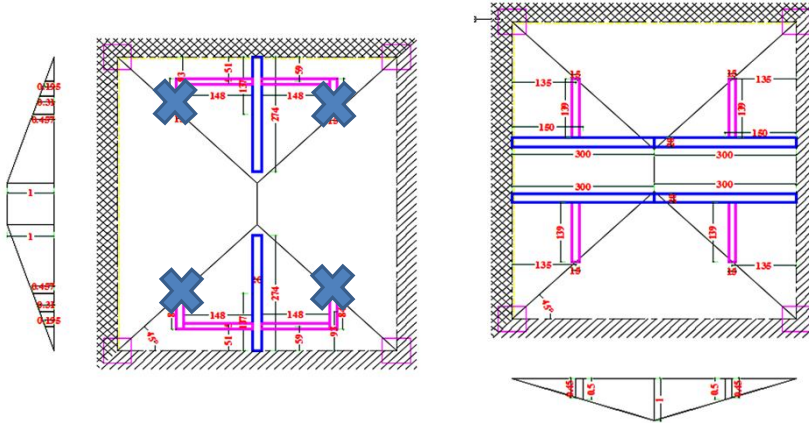
32.75%

Dissipation of internal energy



Zone	Bending moment on yield lines in(k) (x m)	l(m)	θ (radian)	$D=k*I*\theta$ (xm in kNm)
A				
Negative($m'=4m/3$)	1.33	7.00	0.33	3.11
Positive(m)	1.00	7.00	0.33	2.33
B				
Negative($m'=4m/3$)	0.00	7.00	0.33	0.00
Positive(m)	1.00	7.00	0.33	2.33
C				
Negative($m'=4m/3$)	1.33	6.00	0.33	2.67
Positive(m)	1.00	6.00	0.33	2.00
D				
Negative($m'=4m/3$)	0.00	6.00	0.33	0.00
Positive(m)	1.00	6.00	0.33	2.00
Total				14.44

Exerted energy



Zone	N	δ	$E=N*\delta$ (in kNm)
Distributed load			
1-(33.74x6x6)	1,214.37	0.33	404.79
2-(33.74x1x6)	202.40	0.50	30.72
Total			435.51

Equating internal and external energy

$$E = D$$

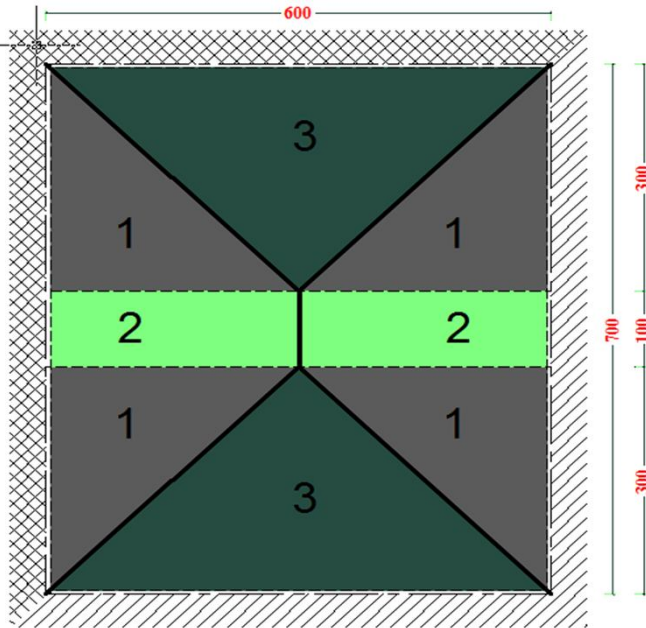
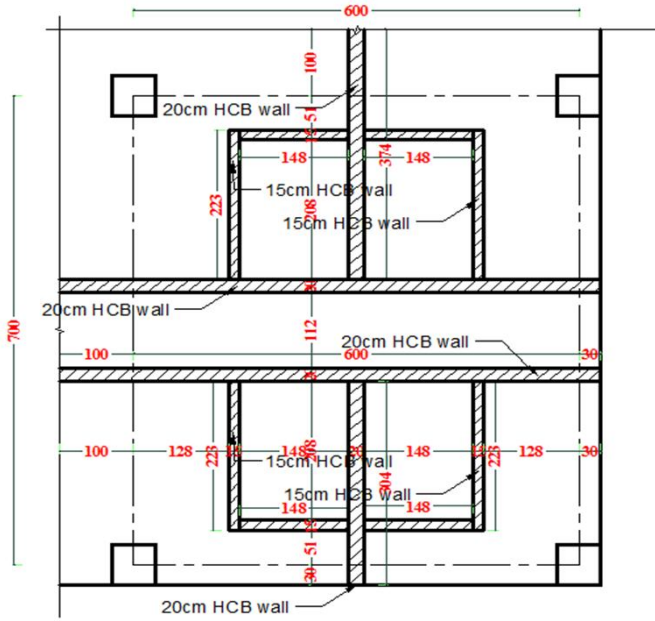
$D=\Sigma(k*I*\theta)$ (xm in kNm)	$E= \Sigma(N*\delta)$ (in kNm)	$m=E/(\Sigma(k*I*\theta))$ (in kNm)	$m'=4m/3$ (in kNm)
14.44	435.51	30.151	40.201

Partition load analysis comparison using virtual work method (modeling as line load and distributed load)

Slab cut from hotel building with high partition load concentration.

Note :-

- Slab depth: 16.00 cm
- Live load: 5.00 kN/m²
- L_x: 6.00 m
- L_y: 7.00 m
- Concrete: C-25
- Steel grade: S-300
- Assume isotropic reinforcement in both direction
- 45° yield line bisects the slab



Load	Volume/area	Density(kN/m ³)	Weight	Unit
Self-load slab	0.16	25	4	kN/m ²
Cement screed	0.03	21	0.63	kN/m ²
Floor finish	0.02	23	0.46	kN/m ²
Plastering	0.025	23	0.575	kN/m ²
			5.665	kN/m ²
20cm HCB wall				
Wall (20cm thick and 3m high)	0.6	14	8.4	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			11.85	kN/m
15cm HCB wall				
Wall (15cm thick and 3m high)	0.45	14	6.3	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			9.75	kN/m

Load combination	DEAD LOAD	LIVE LOAD	1.3DL+1.6LL	Unit
SINGLE LOAD CASE	5.665	5.00	15.36	kN/m ²
20cm HCB wall	11.85		15.41	kN/m
15cm HCB wall	9.75		12.68	kN/m

Zone	N	Area(A=7x6)(m ²)	w=N/A (kN/m ²)
HCB			
15cm			
(12.675x2x1.39)	35.2365	42	0.84
20cm			
(15.405x4x3)	184.86	42	4.40
(15.405x4x2.74)	168.8388	42	4.02
Total			9.26

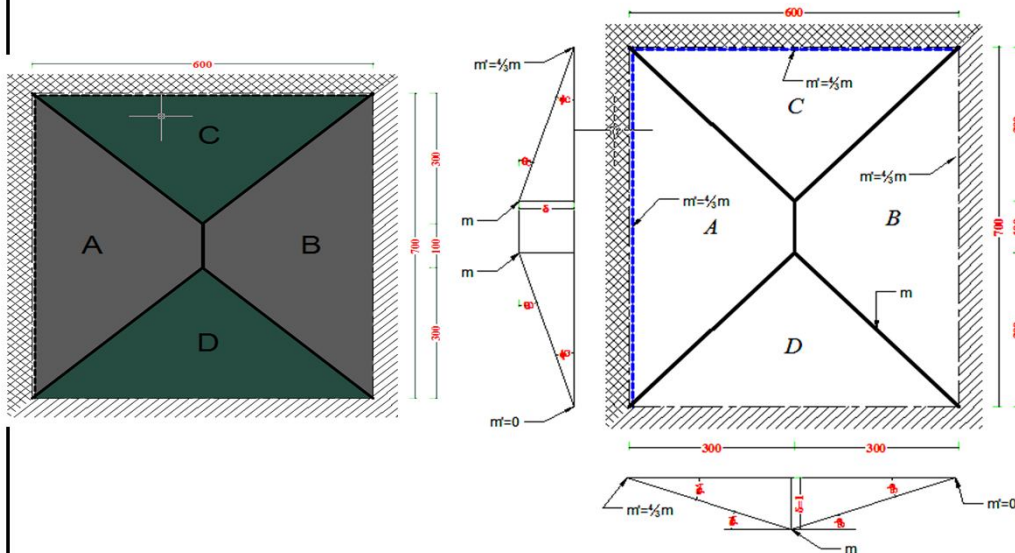
Total distributed load

A+B= **32.84** kN/m²

Percent of partition load

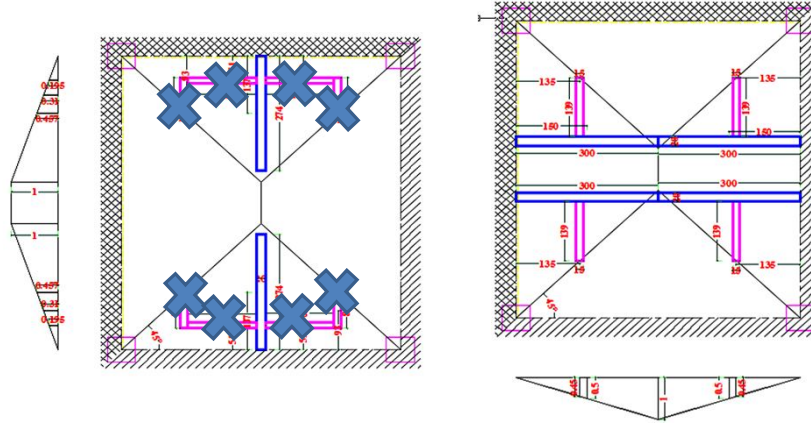
28.19%

Dissipation of internal energy



Zone	Bending moment on yield lines in(k) (x m)	l(m)	θ (radian)	$D=k*I*\theta$ (xm in kNm)
A				
Negative($m'=4m/3$)	1.33	7.00	0.33	3.11
Positive(m)	1.00	7.00	0.33	2.33
B				
Negative($m'=4m/3$)	0.00	7.00	0.33	0.00
Positive(m)	1.00	7.00	0.33	2.33
C				
Negative($m'=4m/3$)	1.33	6.00	0.33	2.67
Positive(m)	1.00	6.00	0.33	2.00
D				
Negative($m'=4m/3$)	0.00	6.00	0.33	0.00
Positive(m)	1.00	6.00	0.33	2.00
Total				14.44

Exerted energy



Zone	N	δ	$E=N*\delta$ (in kNm)
Distributed load			
1-(32.85x6x6)	1,182.42	0.33	394.14
2-(32.85x1x6)	197.07	0.50	30.72
Total			424.86

Equating internal and external energy

$$E = D$$

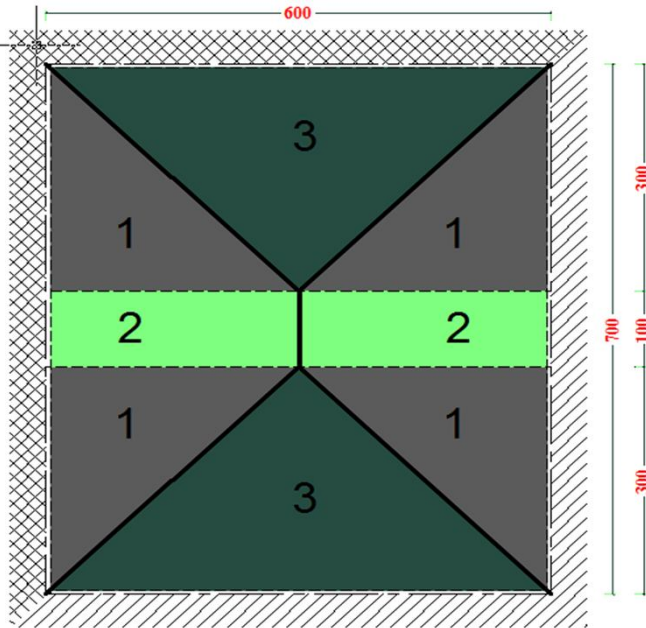
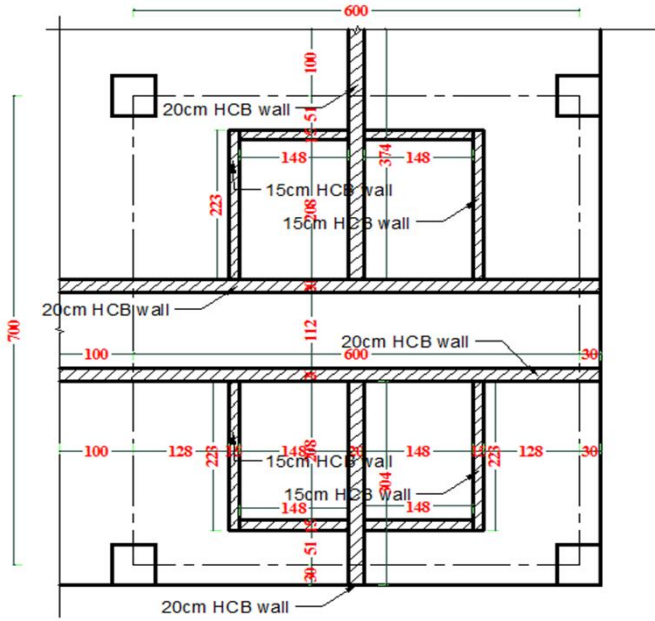
$D=\Sigma(k*I*\theta)$ (xm in kNm)	$E= \Sigma(N*\delta)$ (in kNm)	$m=E/(\Sigma(k*I*\theta))$ (in kNm)	$m'=4m/3$ (in kNm)
14.44	424.86	29.413	39.218

Partition load analysis comparison using virtual work method (modeling as line load and distributed load)

Slab cut from hotel building with high partition load concentration.

Note :-

- Slab depth: 16.00 cm
- Live load: 5.00 kN/m²
- L_x: 6.00 m
- L_y: 7.00 m
- Concrete: C-25
- Steel grade: S-300
- Assume isotropic reinforcement in both direction
- 45° yield line bisects the slab



Load	Volume/area	Density(kN/m ³)	Weight	Unit
Self-load slab	0.16	25	4	kN/m ²
Cement screed	0.03	21	0.63	kN/m ²
Floor finish	0.02	23	0.46	kN/m ²
Plastering	0.025	23	0.575	kN/m ²
			5.665	kN/m ²
20cm HCB wall				
Wall (20cm thick and 3m high)	0.6	14	8.4	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			11.85	kN/m
15cm HCB wall				
Wall (15cm thick and 3m high)	0.45	14	6.3	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			9.75	kN/m

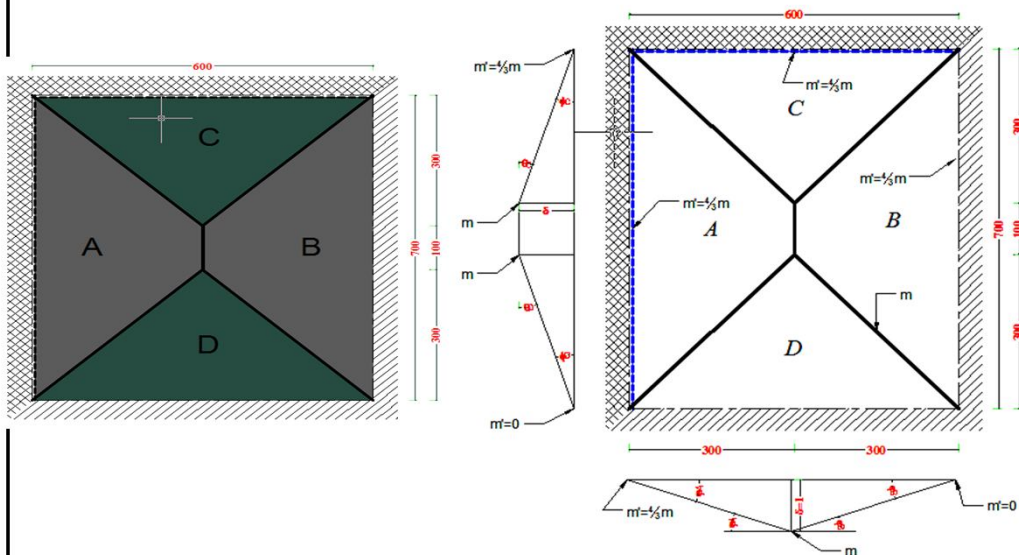
Load combination	DEAD LOAD	LIVE LOAD	1.3DL+1.6LL	Unit
SINGLE LOAD CASE	5.665	5.00	15.36	kN/m ²
20cm HCB wall	11.85		15.41	kN/m
15cm HCB wall	9.75		12.68	kN/m

Zone	N	Area(A=7x6)(m ²)	w=N/A (kN/m ²)
HCB			
15cm			
20cm			
(15.405x4x3)	184.86	42	4.40
(15.405x4x2.74)	168.8388	42	4.02
Total			8.42

Total distributed load $A+B = \boxed{30.52} \text{ kN/m}^2$ 1.438

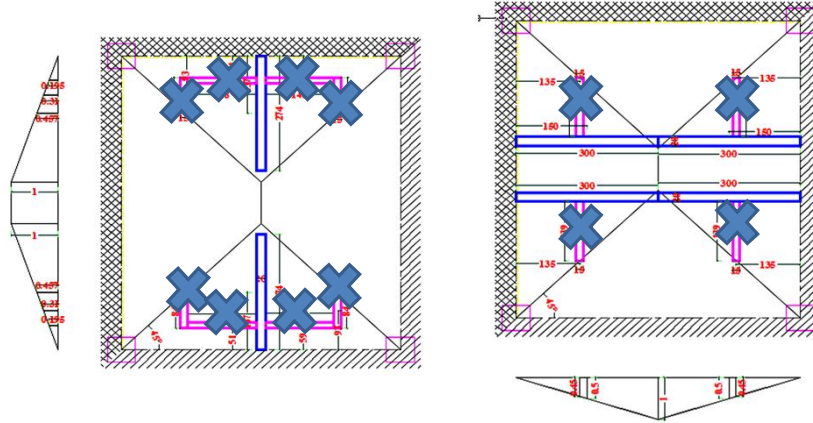
Percent of partition load 27.60%

Dissipation of internal energy



Zone	Bending moment on yield lines in(k) (x m)	l(m)	θ (radian)	$D=k*I*\theta$ (xm in kNm)
A				
Negative($m'=4m/3$)	1.33	7.00	0.33	3.11
Positive(m)	1.00	7.00	0.33	2.33
B				
Negative($m'=4m/3$)	0.00	7.00	0.33	0.00
Positive(m)	1.00	7.00	0.33	2.33
C				
Negative($m'=4m/3$)	1.33	6.00	0.33	2.67
Positive(m)	1.00	6.00	0.33	2.00
D				
Negative($m'=4m/3$)	0.00	6.00	0.33	0.00
Positive(m)	1.00	6.00	0.33	2.00
Total				14.44

Exerted energy



Zone	N	δ	$E=N*\delta$ (in kNm)
Distributed load			
1-(30.52x6x6)	1,098.56	0.33	366.19
2-(30.52x1x6)	183.09	0.50	30.72
Total			396.91

Equating internal and external energy

$$E = D$$

$D=\Sigma(k*I*\theta)$ (xm in kNm)	$E= \Sigma(N*\delta)$ (in kNm)	$m=E/(\Sigma(k*I*\theta))$ (in kNm)	$m'=4m/3$ (in kNm)
14.44	396.91	27.478	36.638

Partition load analysis comparison using virtual work method (modeling as line load and distributed load)

Slab cut from hotel building with high partition load concentration.

Note :-

- Slab depth

16.00	cm
-------	----
- Live load

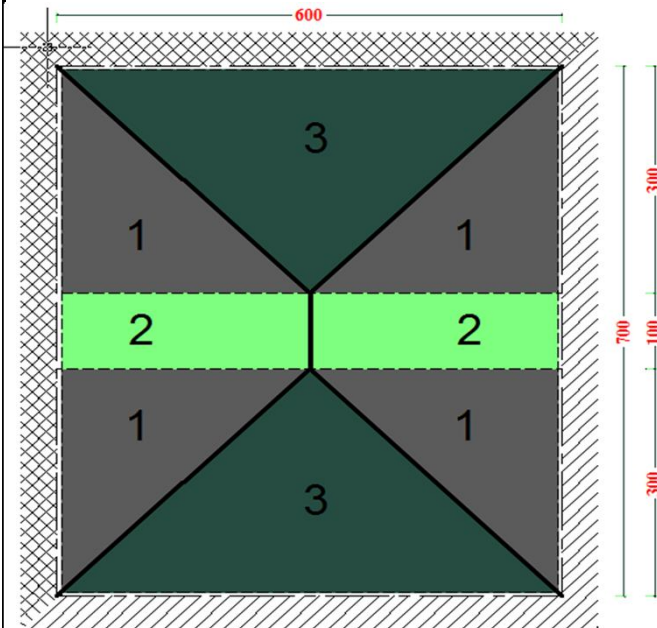
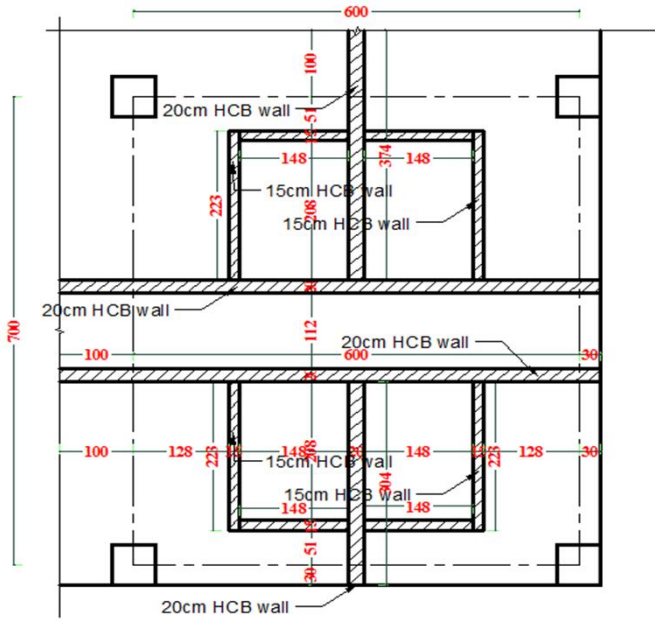
5.00	kN/m ²
------	-------------------
- L_x

6.00	m
------	---
- L_y

7.00	m
------	---
- Concrete

C-25	
------	--
- Steel grade

S-300	
-------	--
- Assume isotropic reinforcement in both direction
- 45° yield line bisects the slab



Load	Volume/area	Density(kN/m ³)	Weight	Unit
Self-load slab	0.16	25	4	kN/m ²
Cement screed	0.03	21	0.63	kN/m ²
Floor finish	0.02	23	0.46	kN/m ²
Plastering	0.025	23	0.575	kN/m ²
			5.665	kN/m ²
20cm HCB wall				
Wall (20cm thick and 3m high)	0.6	14	8.4	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			11.85	kN/m
15cm HCB wall				
Wall (15cm thick and 3m high)	0.45	14	6.3	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			9.75	kN/m

Load combination	DEAD LOAD	LIVE LOAD	1.3DL+1.6LL	Unit
SINGLE LOAD CASE	5.665	5.00	15.36	kN/m ²
20cm HCB wall	11.85		15.41	kN/m
15cm HCB wall	9.75		12.68	kN/m

Zone	N	Area(A=7x6)(m ²)	w=N/A (kN/m ²)
HCB			
15cm			
20cm			
(15.405x4x2.74)	168.8388	42	4.02
Total			4.02

Total distributed load

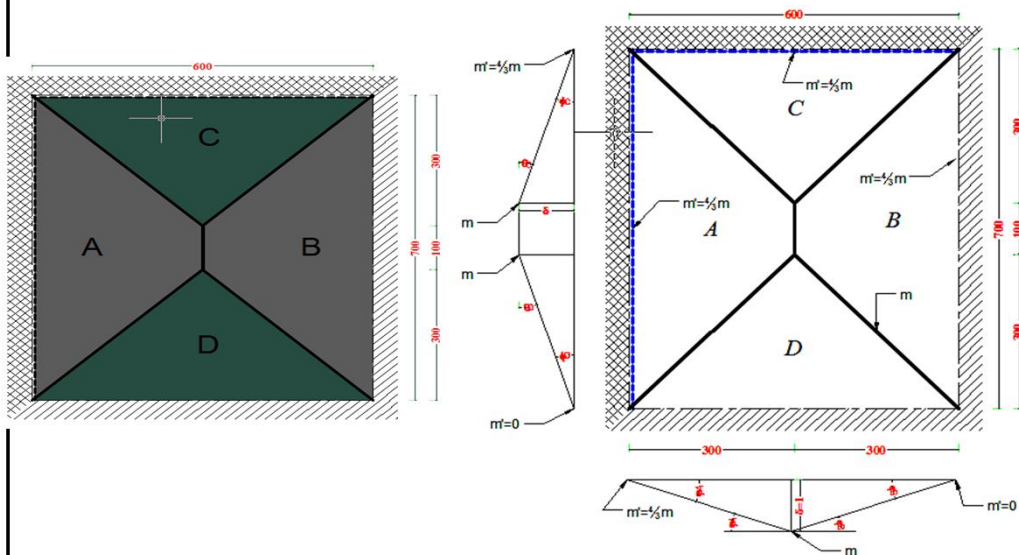
$A+B = 21.15 \text{ kN/m}^2$

1.115

Percent of partition load

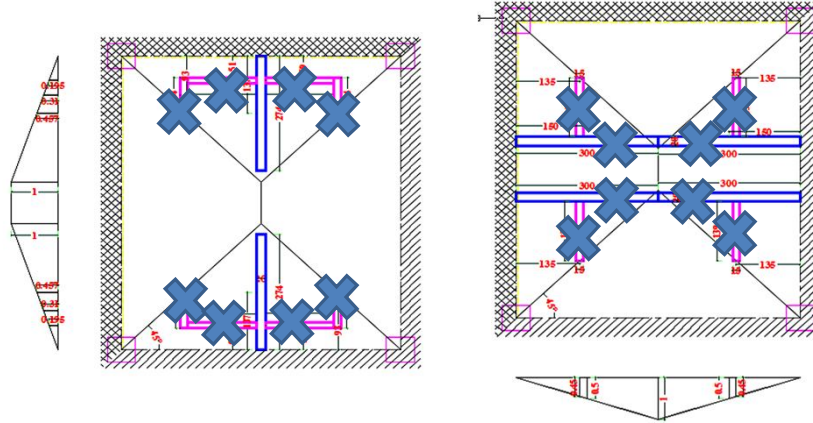
19.01%

Dissipation of internal energy



Zone	Bending moment on yield lines in(k) (x m)	l(m)	θ (radian)	$D=k*I*\theta$ (xm in kNm)
A				
Negative($m'=4m/3$)	1.33	7.00	0.33	3.11
Positive(m)	1.00	7.00	0.33	2.33
B				
Negative($m'=4m/3$)	0.00	7.00	0.33	0.00
Positive(m)	1.00	7.00	0.33	2.33
C				
Negative($m'=4m/3$)	1.33	6.00	0.33	2.67
Positive(m)	1.00	6.00	0.33	2.00
D				
Negative($m'=4m/3$)	0.00	6.00	0.33	0.00
Positive(m)	1.00	6.00	0.33	2.00
Total				14.44

Exerted energy



Zone	N	δ	$E=N*\delta$ (in kNm)
Distributed load			
1-(21.16x6x6)	761.45	0.33	253.82
2-(21.16x1x6)	126.91	0.50	30.72
Total			284.54

Equating internal and external energy

$$E = D$$

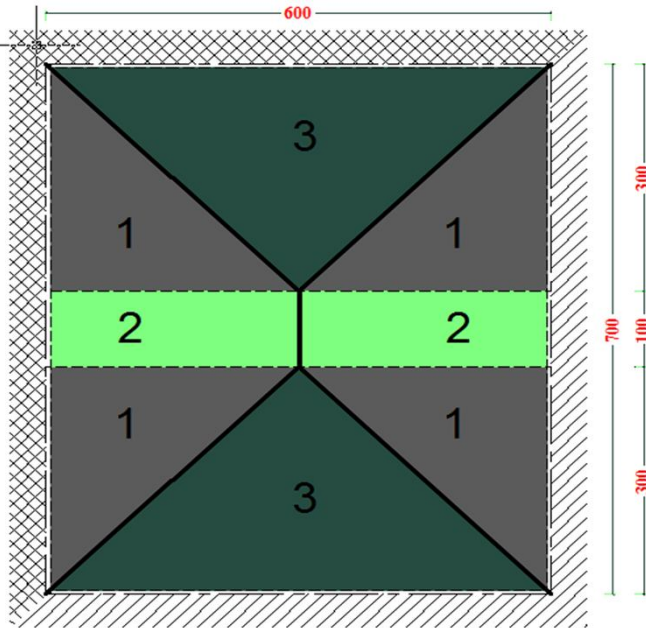
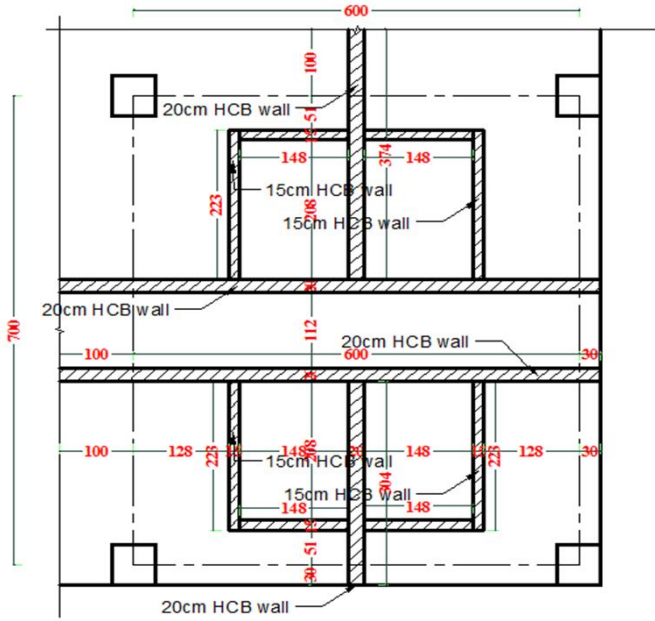
$D=\Sigma(k*I*\theta)$ (xm in kNm)	$E= \Sigma(N*\delta)$ (in kNm)	$m=E/(\Sigma(k*I*\theta))$ (in kNm)	$m'=4m/3$ (in kNm)
14.44	284.54	19.699	26.265

Partition load analysis comparison using virtual work method (modeling as line load and distributed load)

Slab cut from hotel building with high partition load concentration.

Note :-

- Slab depth: 16.00 cm
- Live load: 5.00 kN/m²
- L_x: 6.00 m
- L_y: 7.00 m
- Concrete: C-25
- Steel grade: S-300
- Assume isotropic reinforcement in both direction
- 45° yield line bisects the slab



Load	Volume/area	Density(kN/m ³)	Weight	Unit
Self-load slab	0.16	25	4	kN/m ²
Cement screed	0.03	21	0.63	kN/m ²
Floor finish	0.02	23	0.46	kN/m ²
Plastering	0.025	23	0.575	kN/m ²
			5.665	kN/m ²
20cm HCB wall				
Wall (20cm thick and 3m high)	0.6	14	8.4	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			11.85	kN/m
15cm HCB wall				
Wall (15cm thick and 3m high)	0.45	14	6.3	kN/m
Plastering (2.5cm thick on both sides and 3m high)	0.15	23	3.45	kN/m
			9.75	kN/m

Load combination	DEAD LOAD	LIVE LOAD	1.3DL+1.6LL	Unit
SINGLE LOAD CASE	5.665	5.00	15.36	kN/m ²
20cm HCB wall	11.85		15.41	kN/m
15cm HCB wall	9.75		12.68	kN/m

Zone	N	Area(A=7x6)(m ²)	w=N/A (kN/m ²)
HCB			
15cm			
20cm			
Total			0.00

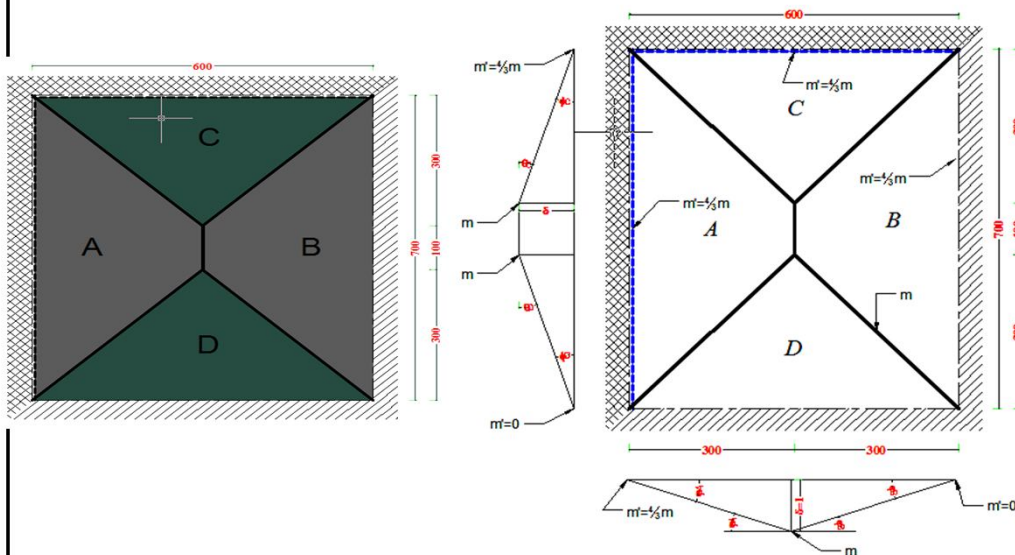
Total distributed load

A+B= **15.36** kN/m²

Percent of partition load

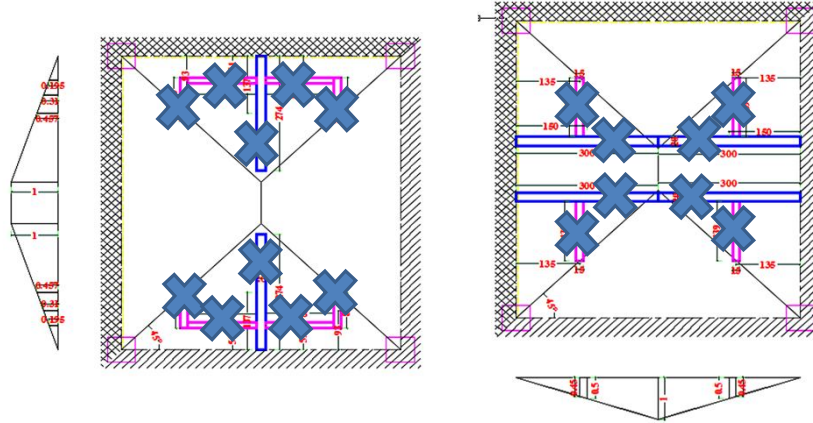
0.00%

Dissipation of internal energy



Zone	Bending moment on yield lines in(k) (x m)	l(m)	θ (radian)	$D=k*I*\theta$ (xm in kNm)
A				
Negative($m'=4m/3$)	1.33	7.00	0.33	3.11
Positive(m)	1.00	7.00	0.33	2.33
B				
Negative($m'=4m/3$)	0.00	7.00	0.33	0.00
Positive(m)	1.00	7.00	0.33	2.33
C				
Negative($m'=4m/3$)	1.33	6.00	0.33	2.67
Positive(m)	1.00	6.00	0.33	2.00
D				
Negative($m'=4m/3$)	0.00	6.00	0.33	0.00
Positive(m)	1.00	6.00	0.33	2.00
Total				14.44

Exerted energy



Zone	N	δ	$E=N*\delta$ (in kNm)
Distributed load			
1-(15.37x6x6)	553.12	0.33	184.37
2-(15.37x1x6)	92.19	0.50	30.72
Total			215.09

Equating internal and external energy

$$E = D$$

$D=\Sigma(k*I*\theta)$ (xm in kNm)	$E= \Sigma(N*\delta)$ (in kNm)	$m=E/(\Sigma(k*I*\theta))$ (in kNm)	$m'=4m/3$ (in kNm)
14.44	215.09	14.891	19.855

12) APPENDEX VI

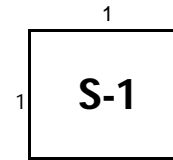
Sample of Deflection computaion using different methods.

Analysis and Design of Two way slabs with defelection check

As per EC

Panel Type Case No.= 3

F_{ck}	25.00	F_{cd}	14.17
F_{yk}	300.00	F_{yd}	260.87



1 -Continuous
0 -Discontinuous

β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30.00	40.00	1.00	40.00

Panel Name	S-1				D [mm]
Depth	Lx [m]	Ly [m]	β_a calc	d [mm]	170.00
	6.00	6.00	40.00	150.00	170.00
D-Load	floor finish	5cm Screed	Weight	Ceiling Plaster	Other.D.Load
	0.54	1.15	4.25	0.73	0.00
Wall Load	L(in)	L(out)	Wall Height	Wall unit weight	q(wall)
	0.00	0.00	0.00	0.00	1.50
Total dead load			8.17		Cover [mm]
Live Load			3.00		15.00
Design load		uls	15.42	sls	9.07
r values	r_1	r_2	r_3	r_4	n_d
	1.33	1.33	1.33	0.00	1.00
Alpha values	α_{xs}	α_{ys}	α_{xf}	α_{yf}	β
	0.039	0.037	0.029	0.028	0.18
Moment	M_{xs}	M_{ys}	M_{xf}	M_{yf}	
	21.65	20.54	16.10	15.54	
k-value	950	910	710	690	
ρ	0.38	0.36	0.28	0.27	
Amin[sq.mm]	252	252	252	252	
Ascal [sq.mm]	569	539	419	404	
Asfinal [sq.mm]	569	539	419	404	
ϕ	# of bars	# of bars	# of bars	# of bars	
8.00	14	13	11	10	
S.max [mm]	340	340	340	340	
S.calc[mm]	80.00	90.00	110.00	120.00	
S.final [mm]	80.00	90.00	110.00	120.00	
	Load Transfer on Beams				Ly/Lx= 1.00
Shear coefficient	β_{vcx}	β_{vdx}	β_{vcy}	β_{vdy}	
	0.32	0.21	0.36	0.00	
Load on Beams	R_{cx}	R_{dx}	R_{cy}	R_{dy}	
Total design load	29.60	19.73	33.30	N.A.	
Live Load	5.76	3.84	6.48	N.A.	
Dead Load	15.68	10.45	17.64	N.A.	

Deflection check

Calculate the moment, M_{QP} , due to quasi-permanent actions at the critical section (i.e. mid-span or at support for cantilever)

M_{xrs}	16.10	I_y/I_x	1.00	1.00	1.05
Asfinal [sq.mm]	419.32	β	0.056548	0.056548	0.058577
M_{xrs}	9.47	Nmm			

Obtain concrete properties, f_{ctm} , and E_{c28} from Table 1

f_{cm}	33.00	N/mm ²
f_{ctm}	2.56	N/mm ²
E_{cm}	31.48	N/mm ²
E_{c28}	33.05	N/mm ²

Calculate creep coefficient, $\varphi(\infty, t_0)$, using either Figure 4 or Annex B (in which case look-up f_{cm} in Table 1)

$\varphi(\infty, t_0)$	2.949353
------------------------	----------

- 1 Calculate long term elastic modulus, E_{eff} from: $E_{eff} = E_{c28}/[1 + \varphi(\infty, t_0)]$
- 2 Calculate effective modulus ratio, α_e from $\alpha_e = E_s/E_{eff}$, where E_s is elastic modulus for reinforcement (200 GPa)
- 3 Calculate depth to neutral axis for uncracked condition, x_u
- 4 Calculate second moment of area for uncracked condition, I_u

E_{eff}	8.37
n	23.90

$$x_u = \frac{\frac{bh^2}{2} + (\alpha_e - 1)(A_s d + A_{s2} d_2)}{bh + (\alpha_e - 1)(A_s + A_{s2})}$$

$$I_u = \frac{bh^3}{12} + bh \left(\frac{h}{2} - x_u \right)^2 + (\alpha_e - 1) [A_s (d - x_u)^2 + A_{s2} (x_u - d_2)^2]$$

x_u	88.48	mm
I_u	447,816,987.16	mm ⁴

Calculate cracking moment, M_{cr} from: $M_{cr} = \frac{0.9 f_{ctm} I_u}{h - x_u}$

(Note the factor 0.9 has been introduced into this method because the loading sequence is not considered)

Mcr	4.00E+00	kNm
e	0.91	

$$x_c = \left\{ \left[(A_s \alpha_e + A_{s2} (\alpha_e - 1))^2 + 2b (A_s d \alpha_e + A_{s2} d_2 (\alpha_e - 1)) \right]^{0.5} - (A_s \alpha_e + A_{s2} (\alpha_e - 1)) \right\} / b$$

$$I_c = \frac{b x_c^3}{3} + \alpha_e A_s (d - x_c)^2 + (\alpha_e - 1) A_{s2} (d_2 - x_c)^2$$

xc	44.81	mm
lc	140,879,389.92	mm ⁴

Calculate flexural curvature $\frac{1}{r_n} = \zeta \frac{M_{QP}}{E_{eff} I_c} + (1 - \zeta) \frac{M_{QP}}{E_{eff} I_u}$

$$S_u = A_s (d - x_u) - A_{s2} (x_u - d_2)$$

$$S_c = A_s (d - x_c) - A_{s2} (x_c - d_2)$$

Su	25,798.50	mm ³
Sc	44,108.21	mm ³
1/rn	7.54E-06	1/mm

Calculate total shrinkage strain ϵ_{cs} from $\epsilon_{cs} = \epsilon_{cd} + \epsilon_{ca}$ where:

$\epsilon_{cd} = k_h \epsilon_{cd,0}$ = Drying shrinkage strain

k_h = Coefficient based on notional size, see Table 2

$\epsilon_{cd,0}$ = Nominal unrestrained drying shrinkage, see Table 1

$\epsilon_{ca} = \beta_{as}(t) \epsilon_{ca}(\infty) = \epsilon_{ca}(\infty)$ for long-term deflection, see Table 1

ecdo	5.12E-04
kh	0.895
ecd	4.58E-04
B	0.43
ecal	38.00
eca	1.63E-05
ecs	4.74E-04

Calculate curvature due to shrinkage strain $1/r_{cs}$ (see Panel 2)

$$\frac{1}{r_{cs}} = \zeta \epsilon_{cs} \alpha_e \frac{S_u}{I_u} + (1 - \zeta) \epsilon_{cs} \alpha_e \frac{S_c}{I_c}$$

$1/r_{cs}$	9.12E-07	1/mm
------------	----------	------

Calculate total curvature $\frac{1}{r_{t,QP}} = \frac{1}{r_n} + \frac{1}{r_{cs}}$

$1/r_{t,qp}$	8.45E-06	1/mm
--------------	----------	------

Calculate quasi-permanent deflection from $\delta_{QP} = KL^2 \frac{1}{r_{t,QP}}$
 where K can be obtained from Figure 6 and L is the span.

dqp	17.20	mm
-----	-------	----

$d=l/200$	20	mm
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Deflection check	OK!!!
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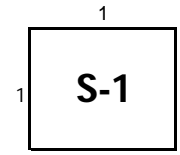
Analysis and Design of Two way slabs with defelection check

As per IS

Panel Type Case No.= 3

F_{ck}	25.00	F_{cd}	11.33
F_{yk}	300.00	F_{yd}	260.87

D&O



1 -Continuous
0 -Discontinuous

β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30.00	40.00	1.00	40.00

Panel Name	S-1				D [mm]
Depth	Lx [m]	Ly [m]	β_a calc	d [mm]	170.00
	6.00	6.00	40.00	150.00	170.00
D-Load	floor finish	5cm Screed	Weight	Ceiling Plaster	Other.D.Load
	0.54	1.15	4.25	0.73	0.00
Wall Load	L(in)	L(out)	Wall Height	Wall unit weight	q(wall)
	0.00	0.00	0.00	0.00	1.50
Total dead load			8.17		Cover [mm]
Live Load			3.00		15.00
Design load	uls = 1.3DL + 1.6LL		15.42		
		DL	8.17		
	SLsshort = DL + 0.5*LL		9.667		
	SLSnormal = DL + LL		11.167		
	SLSlong = DL + 0.3*LL		9.067		
r values	r_1	r_2	r_3	r_4	n_d
	1.33	1.33	1.33	0.00	1.00
Alpha values	α_{xs}	α_{ys}	α_{xf}	α_{yf}	β
	0.039	0.037	0.029	0.028	0.18
Moment	M_{xs}	M_{ys}	M_{xf}	M_{yf}	
	21.65	20.54	16.10	15.54	
k-value	950	910	710	690	
ρ	0.38	0.36	0.28	0.27	
Amin[sq.mm]	252	252	252	252	
Ascal [sq.mm]	575	544	422	407	
Asfinal [sq.mm]	575	544	422	407	
ϕ	# of bars	# of bars	# of bars	# of bars	
8.00	14	13	11	10	
S.max [mm]	340	340	340	340	
S.calc[mm]	80.00	90.00	110.00	120.00	
S.final [mm]	80.00	90.00	110.00	120.00	
Load Transfer on Beams				Ly/Lx= 1.00	
Shear coefficient	β_{vdx}	β_{vdy}	β_{vcy}	β_{vdx}	
	0.32	0.21	0.36	0.00	
Load on Beams	R_{dx}	R_{dy}	R_{cx}	R_{cy}	
Total design load	29.60	19.73	33.30	N.A.	
Live Load	5.76	3.84	6.48	N.A.	
Dead Load	15.68	10.45	17.64	N.A.	

Deflection check

ly/lx	1.00	1.00	1.05
β	0.056548	0.056548	0.058577

Note:- N.A.-Means Not Applicable
F_{ck} for C25 is 25Mpa

	Alpha values	Support	Field	Support	creep coef.
		S1	f	S2	
	αX	0.0390	0.0290	-	φ
Mx	Muls=DL	11.47	8.53	-	
	Mslsshort=DL+0.5*LL	13.57	10.09	-	2.2
	Mslsnormal=DL+LL	15.68	11.66	-	1.6
	Mslslong=DL+0.3*LL	12.73	9.47	-	1.1
	Ec	27,386.13	27,386.13	27,386.13	
	d	150.00	150.00	150.00	
	Mrd check	OK!!!	OK!!!	OK!!!	
Ko	DL	0.0203843	0.0151576	-	
	SLSshort=DL+0.5*LL	0.0241283	0.0179416	-	
	SLSnormal=DL+LL	0.0278723	0.0207256	-	
	SLSlong=DL+0.3*LL	0.0226307	0.0168280	-	
Z	DL	147.25	147.97	150.00	
	SLSshort=DL+0.5*LL	146.74	147.59	150.00	
	SLSnormal=DL+LL	146.22	147.20	150.00	
	SLSlong=DL+0.3*LL	146.94	147.74	150.00	
X	DL	6.871	5.084	0.000	
	SLSshort=DL+0.5*LL	8.161	6.034	0.000	
	SLSnormal=DL+LL	9.461	6.988	0.000	
	SLSlong=DL+0.3*LL	7.644	5.653	0.000	
As	DL	298.3	220.8	0.0	
	SLSshort=DL+0.5*LL	354.4	262.0	0.0	
	SLSnormal=DL+LL	410.8	303.4	0.0	
	SLSlong=DL+0.3*LL	331.9	245.5	0.0	
Amin[sq.mm]	DL	250.0	250.0	250.0	
	SLSshort=DL+0.5*LL	250.0	250.0	250.0	
	SLSnormal=DL+LL	250.0	250.0	250.0	
	SLSlong=DL+0.3*LL	250.0	250.0	250.0	
Asfinal [sq.mm]	DL	298.3	250.0	250.0	
	SLSshort=DL+0.5*LL	354.4	262.0	250.0	
	SLSnormal=DL+LL	410.8	303.4	250.0	
	SLSlong=DL+0.3*LL	331.9	250.0	250.0	
ρ	DL	0.199	0.167	0.167	
	SLSshort=DL+0.5*LL	0.236	0.175	0.167	
	SLSnormal=DL+LL	0.274	0.202	0.167	
	SLSlong=DL+0.3*LL	0.221	0.167	0.167	

	fcr	3.83	3.83	3.83
	lgr	4.09E+08	4.09E+08	4.09E+08
	Mcr	4.62E+06	4.62E+06	4.62E+06
lr	ULS=1.3DL+1.6LL	4.64E+07	3.90E+07	4.11E+07
	SLShort=DL+0.5*LL	5.50E+07	4.08E+07	4.11E+07
	SLNormal=DL+LL	6.38E+07	4.71E+07	4.11E+07
	SLong=DL+0.3*LL	5.15E+07	3.90E+07	4.11E+07
leff	DL	5.64E+07	5.72E+07	4.09E+08
	SLShort=DL+0.5*LL	6.22E+07	5.32E+07	4.09E+08
	SLNormal=DL+LL	6.86E+07	5.69E+07	4.09E+08
	SLong=DL+0.3*LL	5.98E+07	5.30E+07	4.09E+08
MFE	DL	46.25	46.25	46.25
	SLShort=DL+0.5*LL	29.00	29.00	29.00
	SLNormal=DL+LL	33.50	33.50	33.50
	SLong=DL+0.3*LL	27.20	27.20	27.20
	k2	0.10	0.12	0.20
	k1	-	0.000	-
Mcr			4.62E+06	
lr	DL		3.90E+07	
	SLShort=DL+0.5*LL		4.08E+07	
	SLNormal=DL+LL		4.71E+07	
	SLong=DL+0.3*LL		3.90E+07	
leff	DL		5.71E+07	
	SLShort=DL+0.5*LL		5.46E+07	
	SLNormal=DL+LL		5.87E+07	
	SLong=DL+0.3*LL		5.40E+07	
a	DL	ash	1.606	0.1606
	SLShort=DL+0.5*LL	ai(PLS)	13.744	1.3744
	SLNormal=DL+LL	ai(TL)	14.77	1.4772
	SLong=DL+0.3*LL	ai(PLL)	13.03	1.3035
		acp	20.86	2.0856
		along	11.23	1.1231
		atotal	26.00	2.6003
		ali	20.00	2.0000
Deflection check			Revise depth	

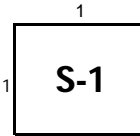
Analysis and Design of Two way slabs with defelection check

As per EBCS 2

Panel Type Case No.= 3

F_{ck}	25.00	F_{cd}	14.17
F_{yk}	300.00	F_{yd}	260.87

D&O



0
1 -Continuous
0 -Discontinuous

β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30.00	40.00	1.00	40.00

Panel Name	S-1				D [mm]
Depth	Lx [m]	Ly [m]	β_a calc	d [mm]	170.00
	6.00	6.00	40.00	150.00	170.00
D-Load	floor finish	5cm Screed	Weight	Ceiling Plaster	Other.D.Load
	0.54	1.15	4.25	0.73	0.00
Wall Load	L(in)	L(out)	Wall Height	Wall unit weight	q(wall)
	0.00	0.00	0.00	0.00	1.50
Total dead load			8.17		Cover [mm]
Live Load			3.00		15.00
Design load		uls	15.42	sls	11.17
r values	r_1	r_2	r_3	r_4	n_d
	1.33	1.33	1.33	0.00	1.00
Alpha values	α_{xs}	α_{ys}	α_{xf}	α_{yf}	β
	0.039	0.037	0.029	0.028	0.18
Moment	Mxs	Mys	Mxf	Myf	
	21.65	20.54	16.10	15.54	
k-value	950	910	710	690	
ρ	0.38	0.36	0.28	0.27	
Amin[sq.mm]	252	252	252	252	
Ascal [sq.mm]	569	539	419	404	
Asfinal [sq.mm]	569	539	419	404	
ϕ	# of bars	# of bars	# of bars	# of bars	
8.00	14	13	11	10	
S.max [mm]	340	340	340	340	
S.calc[mm]	80.00	90.00	110.00	120.00	
S.final [mm]	80.00	90.00	110.00	120.00	
Load Transfer on Beams				Ly/Lx=	1.00
Shear coefficient	β_{vdx}	β_{vdx}	β_{vdy}	β_{vdy}	
	0.32	0.21	0.36	0.00	
Load on Beams	R_{dx}	R_{dx}	R_{dy}	R_{dy}	
Total design load	29.60	19.73	33.30	N.A.	
Live Load	5.76	3.84	6.48	N.A.	
Dead Load	15.68	10.45	17.64	N.A.	

Revise

150.00

Note:- N.A.-Means Not Applicable

F_{ck} for C25 is 20Mpa

Deflection check

$M_{x,ULS}$	16,095,180.96	l_y/l_x	1.00	1.00	1.05
Asfinal [sq.mm]	419.32	β	0.056548	0.056548	0.058577
$M_{x,SLS}$	11,658,139.20	Nmm			
Igr	409,416,666.67	mm ⁴			
fcr	42.50	n/mm ²			
Mcr	51,177,083.33	Nmm			
p	0.28	%			
leff	422,182,480.54	mm ⁴			
ko	0.0286136550				
z	146.11	mm			
x	9.72	mm			
Ecm	30471.58	N/mm ²			
di(iimm)	8.10	mm			
dii	0.00	mm			
dmax	14.60	mm			
d	8.10	mm			
dl	16.20	mm			
dt	24.30	mm			
d=l/200	20	mm			
Deflection check	Revise depth				

	Area	ytop	Aytop
Concrete	170000.00	85.00	14450000.0
Bottom stee	3076.17	150.00	461425.3
	173076.17		14911425.3

Ybar	
	86.15527727

	Area	Yav	lowen axis	Ay ²
Concrete	170000.00	1.16	409416666.7	226893.148
Bottom stee	3076.17	(63.84)	0.0	12538920.7
	173076.17			422182480.5

DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university. All sources of materials used for the thesis have been duly acknowledged.

NAME: Mesgina G/egziabiher

SIGNATURE: _____

PLACE: ADDIS ABABA INSTITUTE TECHNOLOGY- ADDIS ABABA UNIVERSITY, SCHOOL
OF GRADUATE STUDIES,
DEPARTMENT OF CIVIL ENGINEERING

DATE: AUGUST, 2014